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UNITED STATES NAVAL ACADEMY

APPLIED SCIENCE DEPARTMENT

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APPLIED SCIENCE DEPARTMENT

REPORT AS-1-80

MAGNETIC FIELDS OF A HORIZONTAL ELECTRIC DIPOLE IN A SEMI-INFINITE MEDIUM

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AS-1-80	2. GOVT ACCESSION NO. AD-A094 933	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MAGNETIC FIELDS OF A HORIZONTAL ELECTRIC DIPOLE IN A SEMI-INFINITE MEDIUM		5. TYPE OF REPORT & PERIOD COVERED Final Report covering June 1979 to August 1980
		6. PERFORMING ORG. REPORT NUMBER USNA-AS-1-80
7. AUTHOR(s) L. K. CHI, B. R. HOOD, F. A. SKOVE		8. CONTRACT OR GRANT NUMBER(s) N/A
9. PERFORMING ORGANIZATION NAME AND ADDRESS United States Naval Academy Annapolis,		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK-UNIT NUMBERS 11221N/B0005-001 1-2704-110-43
11. CONTROLLING OFFICE NAME AND ADDRESS David W. Taylor Naval Ship R&D Center Attn: Code 2704 Annapolis, MD 21402		12. REPORT DATE August 1980
		13. NUMBER OF PAGES 68
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) N/A		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved For Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

- Horizontal Electric Dipole
- Magnetic Field
- Subsurface to Air
- Subsurface to Subsurface
- Point Dipole
- Finite Length Dipole
- Modified Image Theory

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Various formulae for magnetic fields of horizontal electric dipoles in semi-infinite medium have been derived. In the interest of providing the ability to evaluate the magnetic field strength interactively at on-site field locations, reduced expressions, which are valid in the quasi-static range, for the magnetic field were used in developing computer generated plots.

Existing expressions were used to plot the field strength for AC and point DC dipoles with the receiver either in the medium or above the medium. In order to

Item 20 continued.

plot the special case of a finite length DC dipole with the receiver above the medium, the reduced expressions had to be derived. These new expressions, in addition to agreeing with Kraichman's point dipole expressions which are valid at a distance, also are valid with the receiver directly above the source.

ACKNOWLEDGEMENT

The work presented here was developed under the sponsorship of the David W. Taylor Naval Ship Research and Development Center, Annapolis Laboratory.

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LIST OF ABBREVIATIONS

d - $\delta(1-i) = 2/\gamma$

h - depth of dipole source

H_x - magnetic field component in the x direction

H_y - magnetic field component in the y direction

H_z - magnetic field component in the z direction

H_T - total magnetic field in the direction of the earth's magnetic field

I - current

K_1 - $[\rho^2 + (z-bh)^2]^{1/2}$

K_2 - $[\rho^2 + (1+z-bh)^2]^{1/2}$

K_3 - $[\rho^2 + b^2 (z+h)^2]^{1/2}$

K_4 - $\{\rho^2 + [d-b(z+h)]^2\}^{1/2}$

K_{11} - $[(x+L/2)^2 + y^2 + (d+z-bh)^2]^{1/2}$

K_{12} - $[(x-L/2)^2 + y^2 + (d+z-bh)^2]^{1/2}$

K_{21} - $[(x+L/2)^2 + y^2 + (z-bh)^2]^{1/2}$

K_{22} - $[(z-L/2)^2 + y^2 + (z-bh)^2]^{1/2}$

L - dipole length

P - IL, dipole movement of a point dipole

R - $(x^2+y^2+z^2)^{1/2}$

R_1 - $[\rho^2 + (z-h)^2]^{1/2}$

R_2 - $[\rho^2 + (z+h)^2]^{1/2}$

γ - $(i\ \omega\ \mu_0\ \sigma)^{1/2}$ propagation constant for the lower half medium

δ - skin depth of the lower half medium

ρ - $(x^2+y^2)^{1/2}$

σ - conductivity of the lower half medium

μ_0 - permeability of the lower half medium

ω - angular frequency

EXECUTIVE SUMMARY

THE MAGNETIC FIELDS OF A HORIZONTAL ELECTRIC DIPOLE IN A SEMI-INFINITE MEDIUM

OBJECTIVE

The objective of this report is to provide a means of predicting, interactively, the magnetic fields in a quasi-static range due to a submerged horizontal electric dipole.

APPROACH

Simple engineering expression were used, or developed, to predict the magnetic fields. These expressions were programmed in ANSI 77 Fortran to produce graphics displays on a Tektronix terminal.

RESULTS

The computer programs can be used to find the magnetic fields along certain chosen paths in the upper half or in the lower half medium. The corresponding magnetic curves for each path can then be plotted. The systems which predict the results for DC sources have been utilized extensively by the David W. Taylor Naval Ship Research and Development Center, Annapolis, Maryland.

CONCLUSIONS AND RECOMMENDATIONS

Computer simulations are viable tools to evaluate magnetic fields in an interactive environment. In order to fully analyze experimental data, it is recommended that the models be modified to include multi-layer effects.

CAUTION: This document was prepared as part of a larger effort. The contents should not be taken out of context of that larger effort.

ABSTRACT

Various formulae for magnetic fields of horizontal electric dipoles in a semi-infinite medium have been derived. In the interest of providing the ability to evaluate the magnetic field strength interactively at on-site field locations, reduced expressions, which are valid in the quasi-static range, for the magnetic field were used in developing computer generated plots.

Existing expressions were used to plot the field strength for AC and point DC dipoles with the receiver either in the medium or above the medium. In order to plot the special case of a finite length DC dipole with the receiver above the medium, the reduced expression had to be derived. These new expressions, in addition to agreeing with Kraichman's point dipole expressions which are valid at a distance, also are valid with the receiver directly above the source.

ADMINISTRATIVE INFORMATION

This project was supported by the Annapolis Laboratory of the David W. Taylor Naval Ship Research and Development Center.

INTRODUCTION

Numerous papers have been published to give various approximate expressions for magnetic field strengths in various configurations. There is a growing need to evaluate the magnetic field strengths instantaneously and interactively so that curves for magnetic fields at different heights, different distances, different frequencies, and different orientations in relationship with the earth's magnetic field can be produced instantly. In this report, the author's develope a set of computer programs to evaluate the magnetic fields generated by a submerged horizontal electric dipole. Only the quasi-stati range of expressions is considered throughout the report.

As shown in Figure 1, a horizontal electric dipole (HED) of finite length L angular frequency ω, is located at depth h ($h < 0$) between $-L/2$ and $L/2$ parallel to the x-axis in the positive x-direction. The plane $z=0$ separates the upper region ($z > 0$) of air from the lower region of the conducting medium with conductivity α and permeability μ_0. The observation point (x,y,z) is either in the air or in the medium. For simplicity, Kraichman's approximate formulae[1] and Bannister and Dube's modified image theory results[2], instead of the more exact numerical results, are used. A collection of the reports written by Bannister and his co-worker can be found in reference 3. The expressions for a finite length DC dipole are derived from modified image theory results as a limiting case of an AC dipole. Rectangular coordinates are used throughout the report. The cylindrical coordinate expressions found in references 1 and 2, are changed to rectangular coordinates.

The computer programs are written in 77 Ansi Fortran. In each case for an AC dipole, the computer program gives the moduli of each of the three components, the moduli of the component in the direction of the earth's magnetic field, the real part of this projection, and the phase of the projection. In all of the AC cases the frequency is assumed to be 1 Hz, the dipole current is 50 amperes, and the direction of the earth's magnetic field is in the negative y direction. In the case of a DC dipole, the computer program gives the three components, and the component in the direction of the earth's magnetic field. Curves of magnetic fields are produced by using the graphics package[4] developed for the Textronix 4051 at the U. S. Naval Academy. The measuring distances, heights, orientations, and dipole frequencies can be specified interactively at the execution time of the programs.

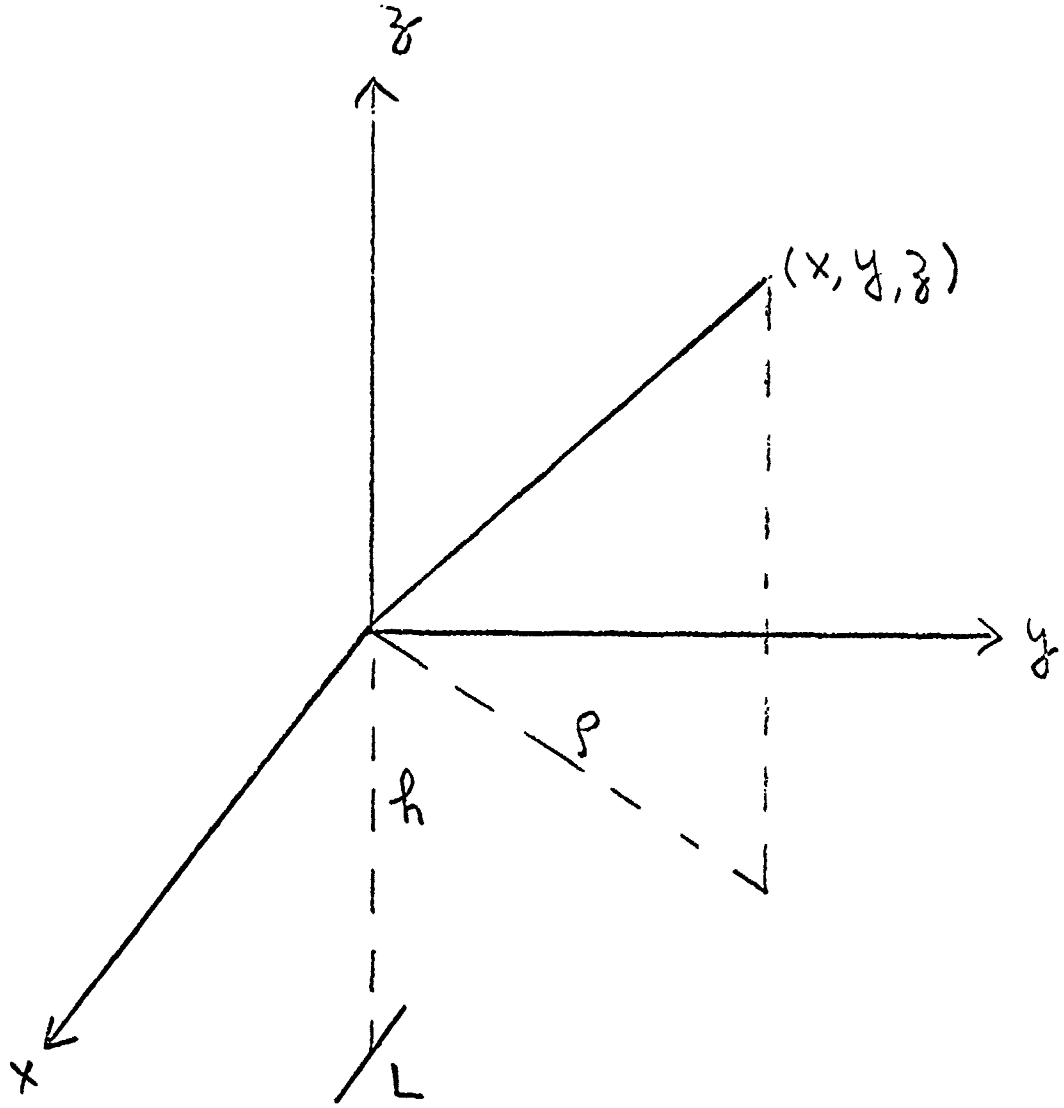


Fig. 1 Dipole configuration in a semi-infinite medium

The programs are designed so as to generate output which is stored in ta files. These data files may then be used for analysis, or they may serve as input to the graphics package to plot the curves. This approach was taken so that the programs can be used even if plotting capability is not readily available. A complete listing of all the programs with instructions for their use can be found in Appendix A.

EQUATIONS

Nine different configurations of field strength evaluations will be discussed. The first six cases pertain to AC sources. Modified image theory results are used in the first three of these, while the second three describe the field in limited ranges. The remaining three cases refer to DC sources.

(A) Finite length AC dipole subsurface to air propagation (Modified Image Theory).

Bannister and Dube[2] arrived at the following quasi-static formulae by employing finitely conducting earth-image theory techniques.

These specific expressions are in simple algebraic form, are valid for the quasi-static range, and can be found on page 10 of reference 2.

$$H_x = \frac{Iy}{4\pi} e^{\gamma ah} \left\{ \frac{1}{(x-\frac{L}{2})^2+y^2} \left[\frac{d+z-bh}{K_{12}} - \frac{z-bh}{K_{22}}\right] - \frac{1}{(x+\frac{L}{2})^2+y^2} \left[\frac{d+z-bh}{K_{11}} - \frac{z-bh}{K_{21}}\right]\right\} \tag{1}$$

$$H_y = \frac{I}{4\pi} e^{\gamma ah} \left\{ \frac{d+z-bh}{y^2+(d+z-bh)^2} \left[\frac{x+\frac{L}{2}}{K11} - \frac{x-\frac{L}{2}}{K12}\right] - \frac{z-bh}{y^2+(z-bh)^2} \left[\frac{x+\frac{L}{2}}{K_{21}} - \frac{x-\frac{L}{2}}{K_{22}}\right] + \frac{x+\frac{L}{2}}{y^2+(x+\frac{L}{2})^2} \left[\frac{d+z-bh}{K_{11}} - \frac{z-bh}{K_{22}}\right]\right\} \tag{2}$$

$$H_z = -\frac{Iy}{4\pi} e^{\gamma ah} \left\{ \frac{1}{y^2+(d+z-bh)^2} \left[\frac{x+\frac{L}{2}}{K_{11}} - \frac{x-\frac{L}{2}}{K_{12}}\right] - \frac{1}{y^2+(z-bh)^2} \left[\frac{x+\frac{L}{2}}{K_{21}} - \frac{x-\frac{L}{2}}{K_{22}}\right]\right\} \tag{3}$$

Bannister and Dube chose the following values for the constants a and b:

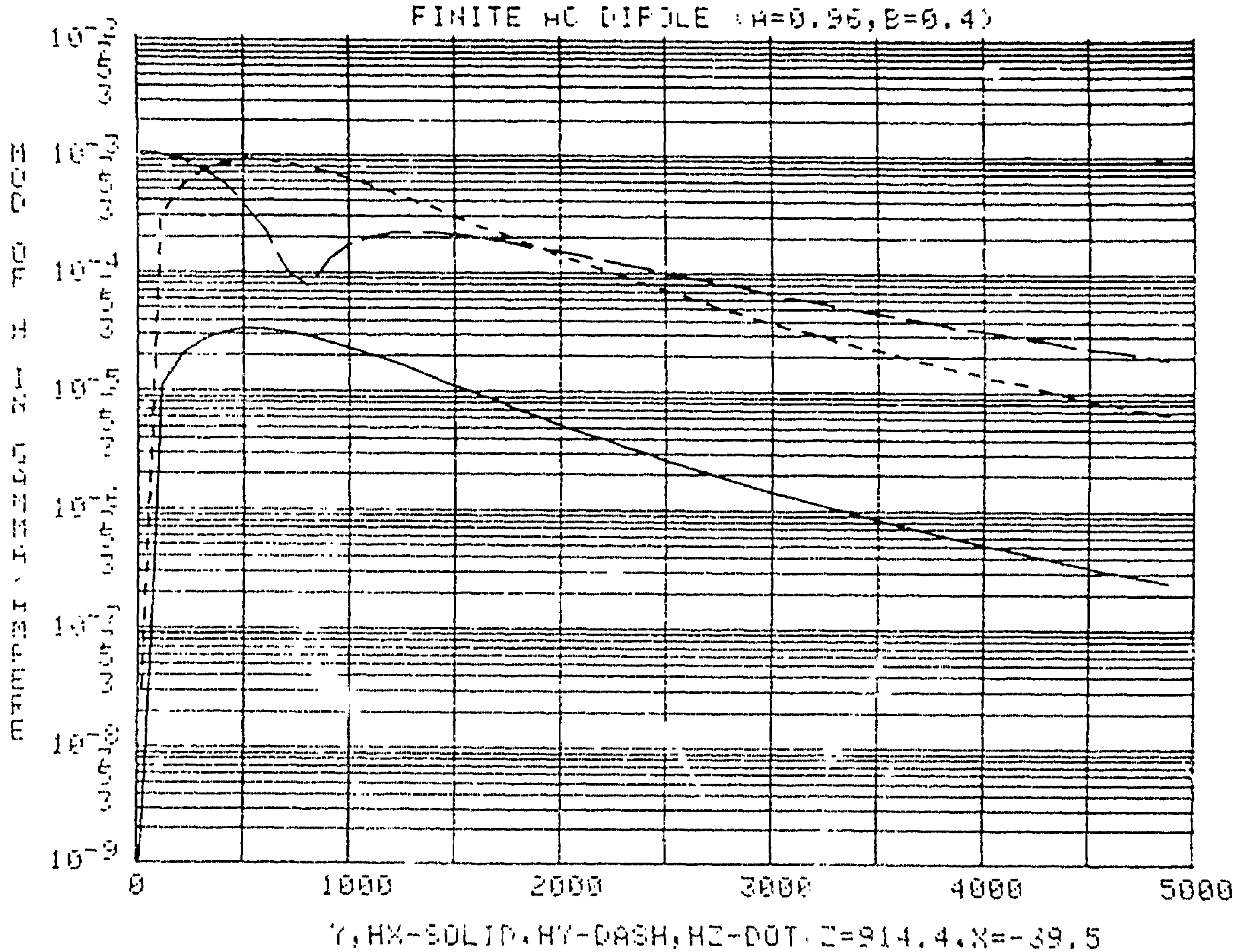
$a = 0$ and $b = 1$ for $R \ll \delta$ and $|h| \ll \delta$,

$a = 0.30$ and $b = 0.96$ for R/δ less than approximately 1,

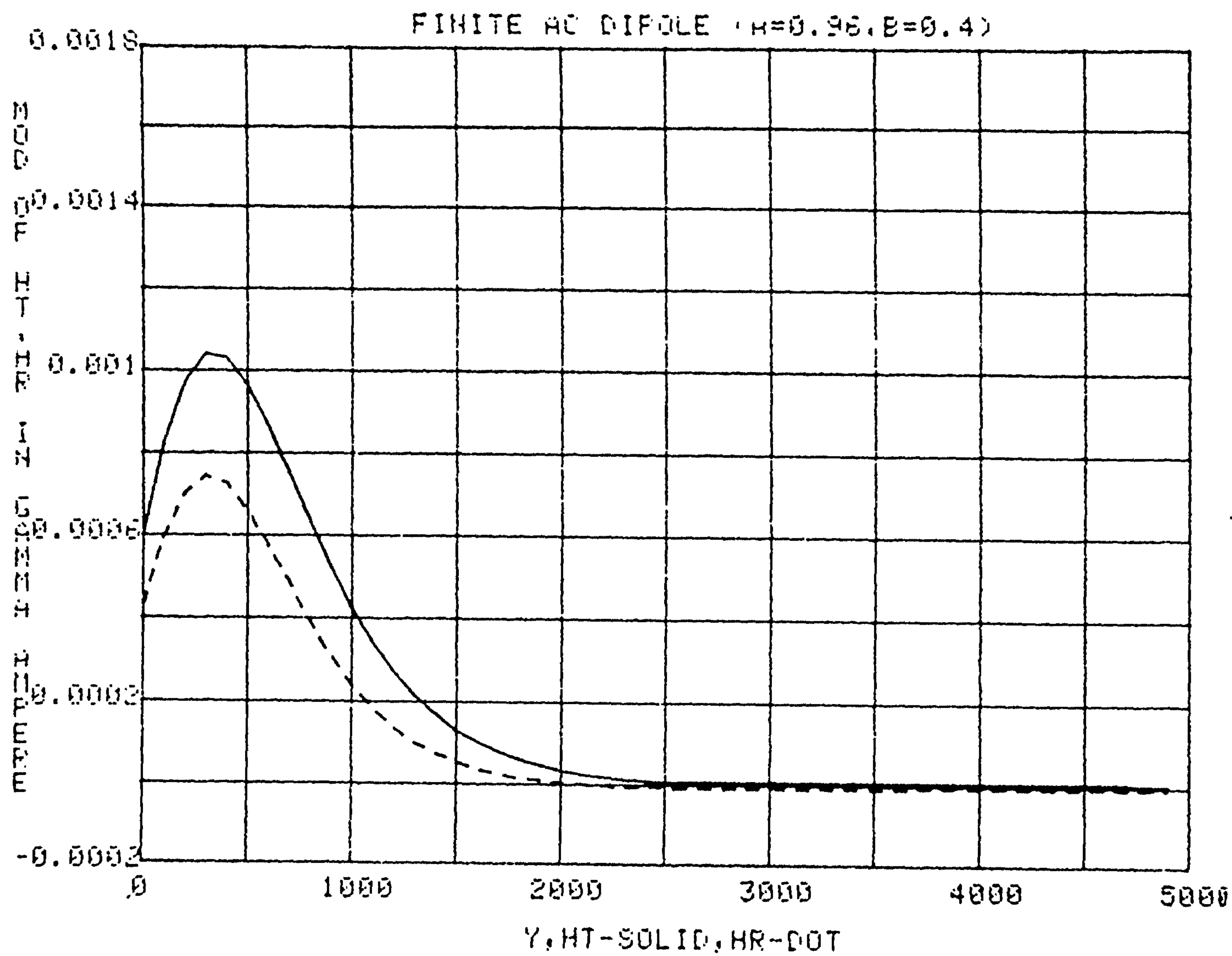
$a = 0.96$ and $b = 0.40$ for R/δ between approximately 1 and 10,

$a = 1.0$ and $b = 0$ for $R > |3h|$.

The name of the program used to predict the magnetic field strength for this case is ACF (finite length AC dipole subsurface to air). The output is shown in Figures 2, 3 and 4. The field is measured along the path, $x = -39.5$m, $z = 914.4$m, and $0 < y \leq 5000$m. Figure 2 depicts the absolute values of the three components of the magnetic field. Figure 3 gives the modulus of the projection of the magnetic field in the direction of the earth's field and the real part of that projection. Figure 4 is a graph of the phase of the projection.

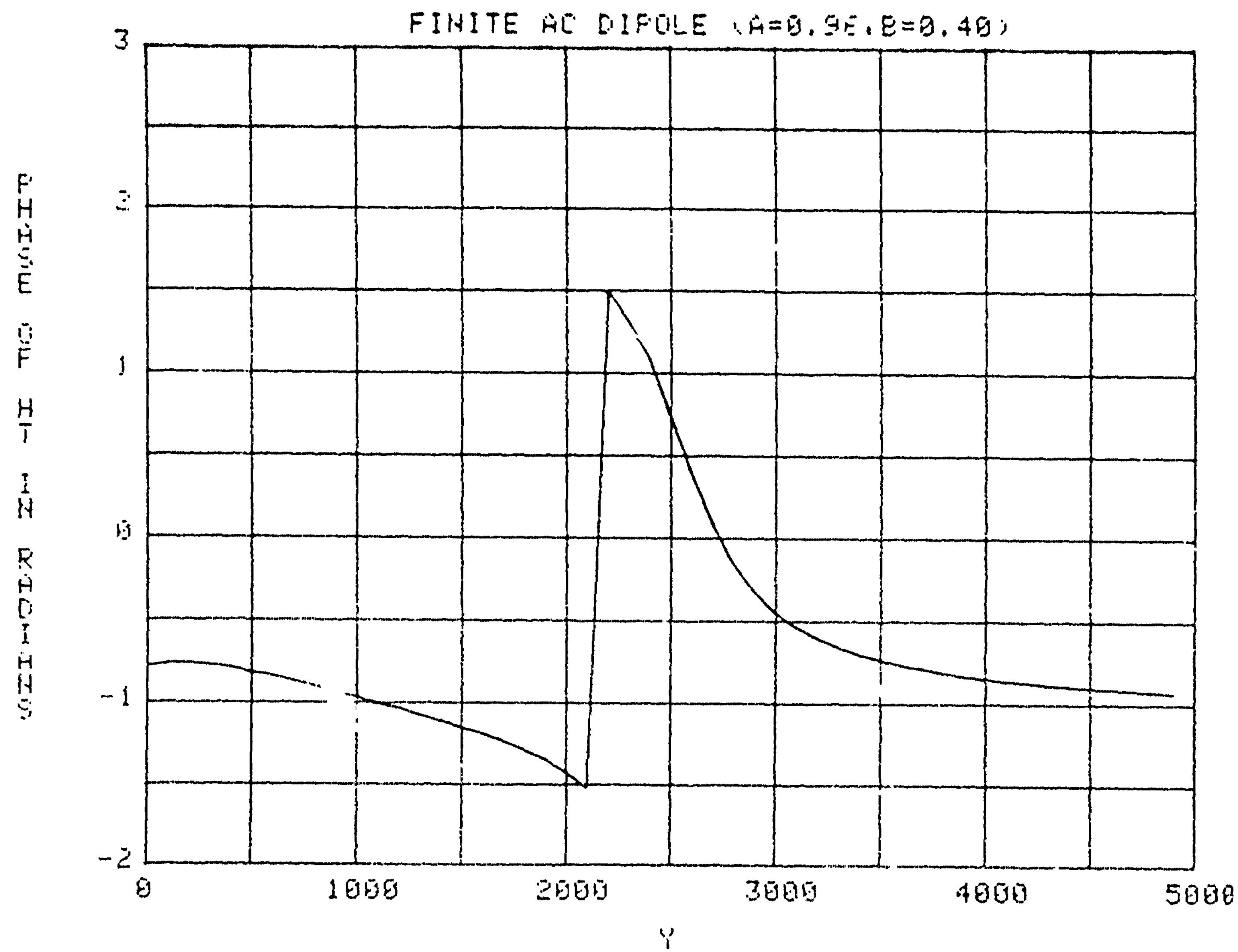


FINITE HC DIPOLE (A=0.96,B=0.4)
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
0
1000
2000
3000
4000
5000
Y,HX-SOLID,HY-DASH,HZ-DOT,Z=914.4,X=-39.5



FINITE AC DIPOLE (A=0.96,B=0.4)
MOD OF HT,HR IN GAMMA AMPERE
0.0018
0.0014
0.001
0.0006
0.0002
-0.0002
0
1000
2000
3000
4000
5000
Y,HT-SOLID,HR-DOT

Figure 3



FINITE AC DIPOLE (A=0.95,B=0.40)
PHASE OF HT IN RADIANS
3
2
1
0
-1
-2
0
1000
2000
3000
4000
5000
Y

Figure 4

(B) Point AC dipole subsurface to air propagation (Modified Image Theory).

The expressions for the magnetic field subsurface to air propagation due to a point AC dipole are given, in cyclindrical coordinates on page 6 of reference 2. As pointed out in reference 2, these expressions can be derived from the corresponding finite length DC expressions (1), (2), and (3), as the measurement distance becomes much greater than the source length L. In the interest of consistency, the expressions given in reference 2 have been transformed into rectangular coordinates.

$$H_x = \frac{Pxy}{4\pi\rho^2} e^{\gamma ah} \left[\frac{d+z-bh}{K_2^3} - \frac{z-bh}{K_1^3} + \frac{2}{\rho 2}\left(\frac{d+z-bh}{K_2} - \frac{z-bh}{K_1}\right)\right] \tag{4}$$

$$H_y = \frac{P}{4\pi} e^{\gamma ah} \left[\left(\frac{d+z-bh}{K_2^3} - \frac{z-bh}{K_1^3}\right) \frac{y^2}{\rho 2} + \frac{y^2-x^2}{\rho 4}\left(\frac{d+z-bh}{K_2} - \frac{z-bh}{K_1}\right)\right] \tag{5}$$

$$H_z = \frac{Py}{4\pi} e^{\gamma ah} \left(\frac{1}{K_1^3} - \frac{1}{K_2^3}\right) \tag{6}$$

The constants a and b are again loosely defined as in Case A. The name of the program which produces the output for this case is ACP (point AC dipole subsurface to air). Sample outputs of ACP are shown in Figures 5, 6 and 7. All the constants, as well as the three output examples, are the same as the previous representation for a finite dipole.

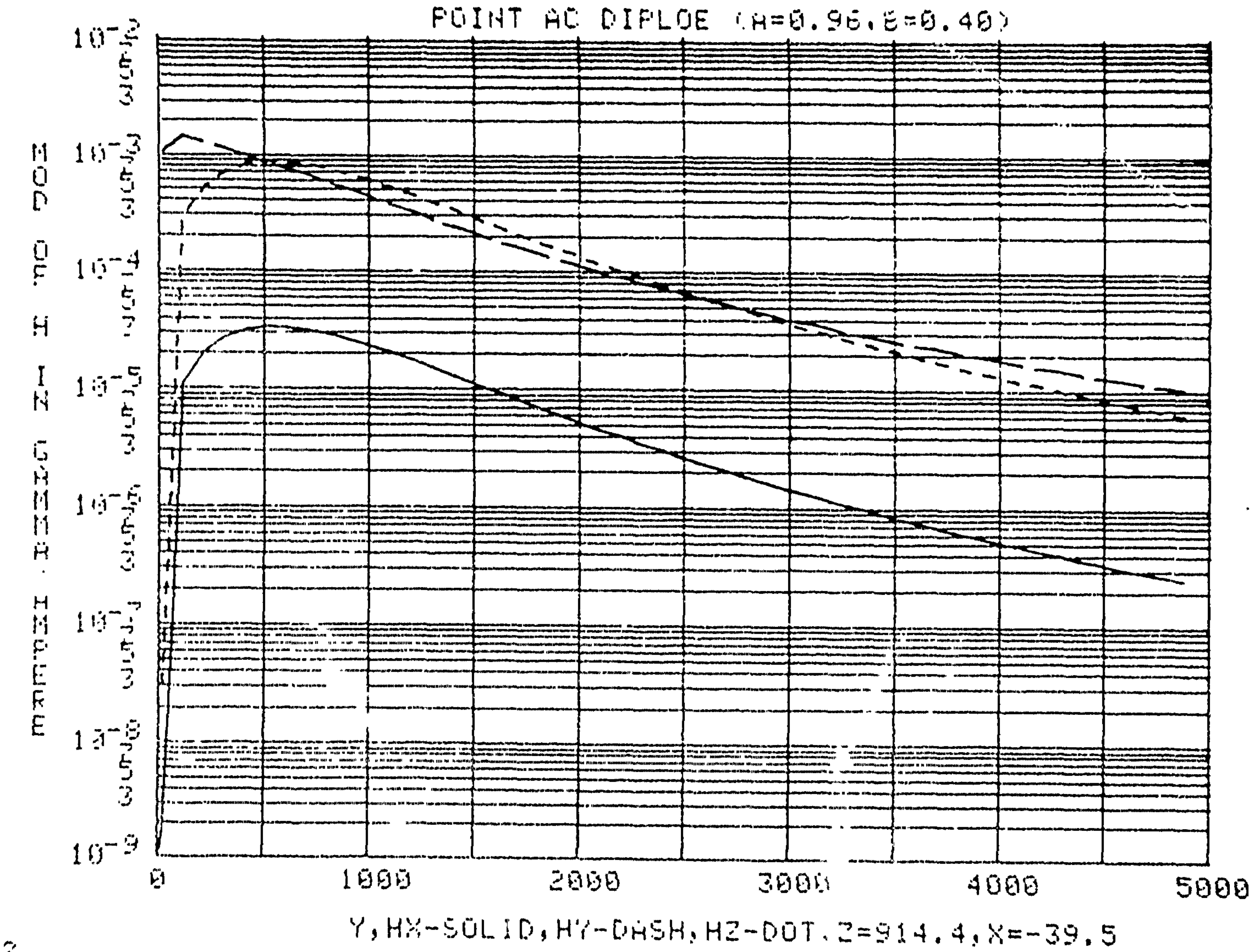

POINT AC DIPLOE (A=0.96,B=0.40)
Y,HX-SOLID,HY-DASH,HZ-DOT,Z=914.4,X=-39.5
0
1000
2000
3000
4000
5000

Figure 5

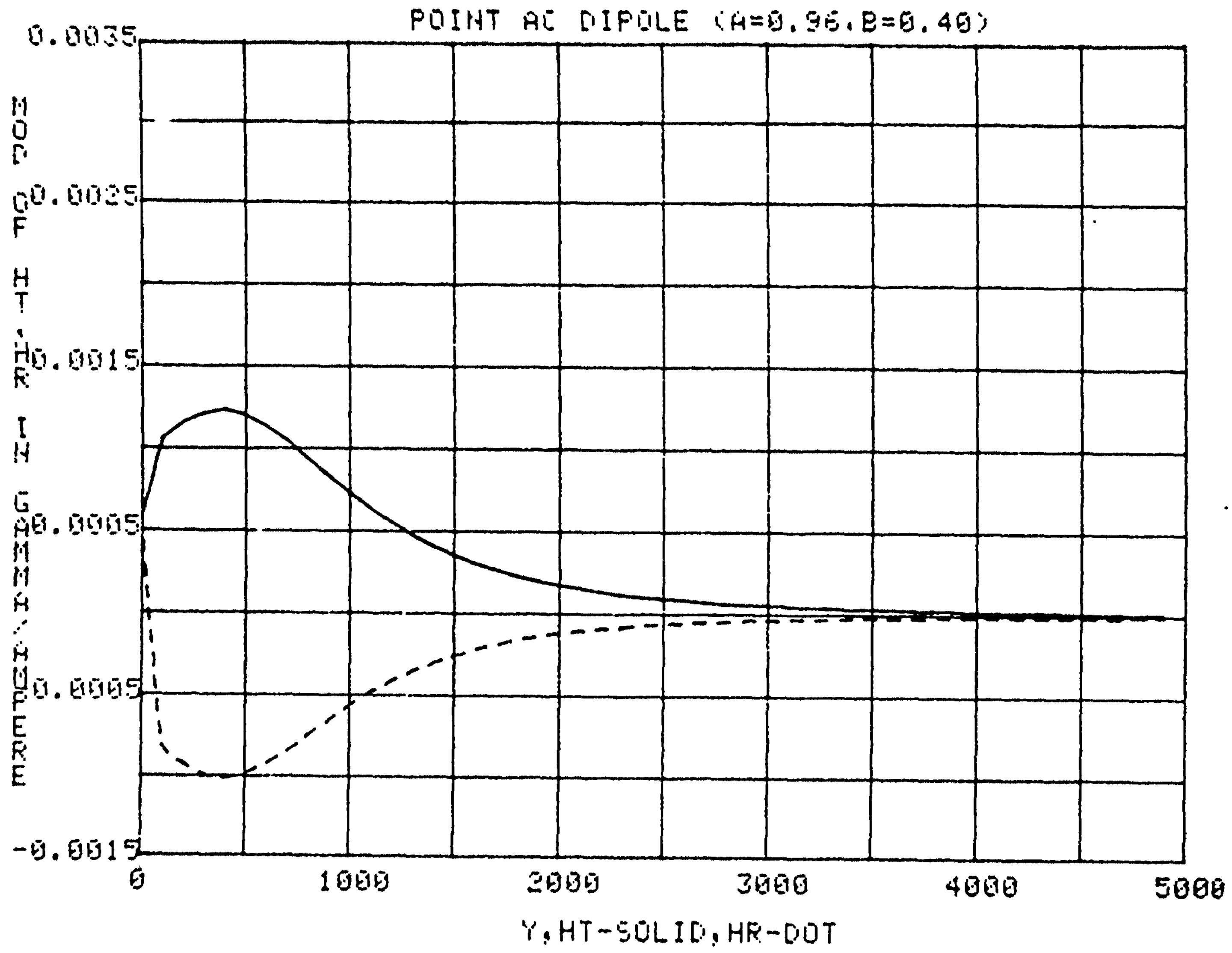

POINT AC DIPOLE (A=0.96,B=0.40)
MOD OF HT,HR IN GAMMA/AMPERE
0.0035
0.0025
0.0015
0.0005
-0.0005
-0.0015
0
1000
2000
3000
4000
5000
Y,HT-SOLID,HR-DOT

Figure 6

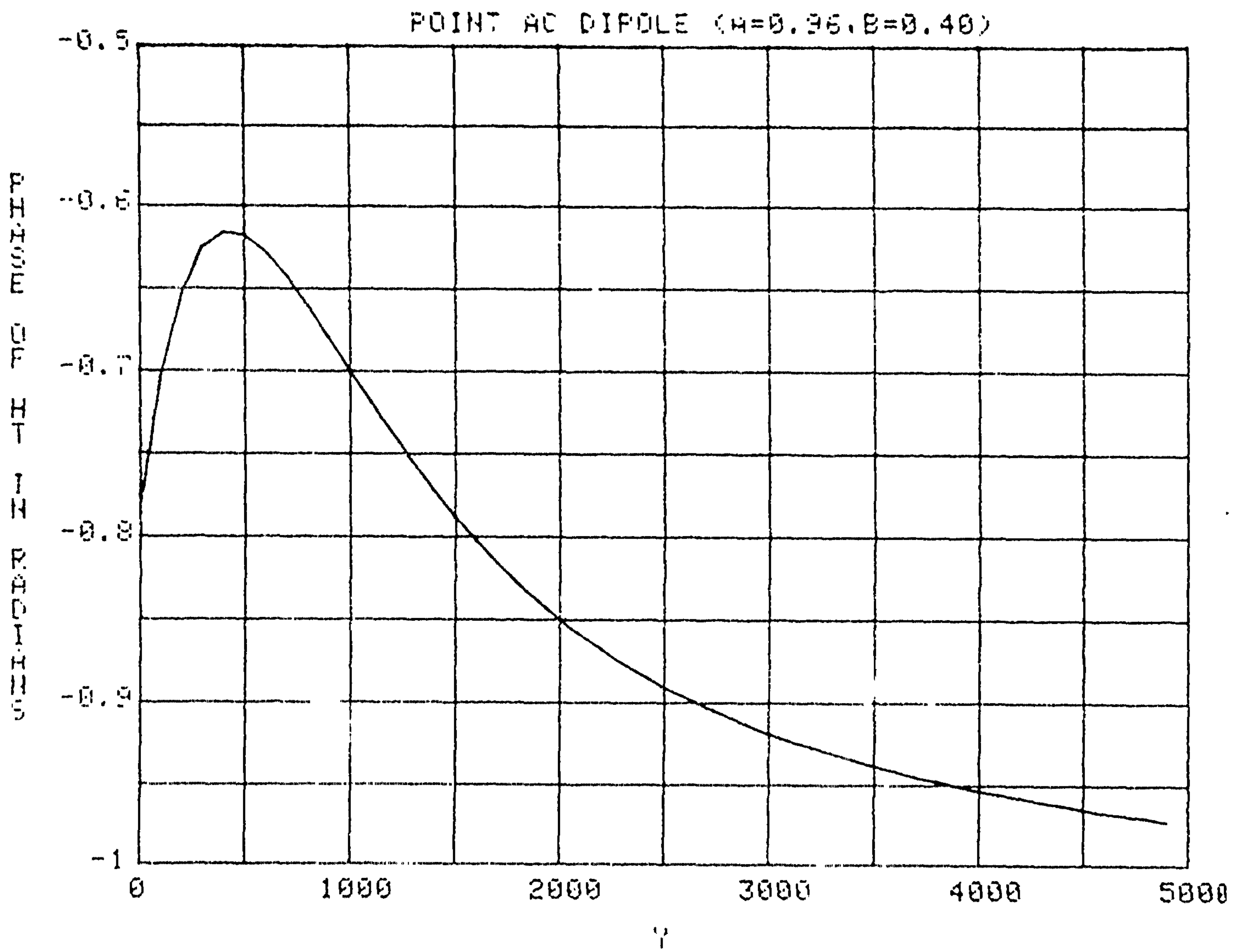

POINT AC DIPOLE (A=0.96,B=0.40)
PHASE OF HT IN RADIANS
-0.5
-0.6
-0.7
-0.8
-0.9
-1
0
1000
2000
3000
4000
5000
Y

Figure 7

(C) Point AC dipole subsurface to subsurface propagation (Modified Image Theory).

The expressions for the magnetic field subsurface to subsurface propagation due to a point AC dipole are given, in cylindrical coordinates, on pages 13 and 14 of reference 2. In rectangular coordinates, they become:

$$H_x = \frac{Pxy}{4\pi\rho^2}\left\{\frac{z+h}{R_2^3}(1+\gamma R_2)e^{-\gamma R_2} + e^{\gamma a(z+h)}\left[\frac{2d-2b(z+h)}{K_4\rho^2} + \frac{2b(z+h)}{\rho^2 K_3} + \frac{d-b(z+h)}{K_4^3}\right]\right\} \tag{7}$$

$$H_y = \frac{P}{4\pi}\left\{-\frac{z-h}{R_1^3}(1+\gamma R_1)e^{-\gamma R_1} - \frac{(z+h)x^2}{\rho^2 R_2^3}(1+\gamma R_2)e^{-\gamma R_2} + e^{a(z+h)}\left[\frac{d-b(z+h)}{K_4\rho^4}(y^2-x^2) + \frac{b(z+h)(y^2-x^2)}{K_3\rho^4} + \frac{d-b(z+h)}{K_4^3}\frac{y^2}{\rho^2}\right]\right\} \tag{8}$$

$$H_z = \frac{Py}{4\pi\rho}\left\{\frac{e^{-\gamma R_1}}{R_1^3}(1+\gamma R_1) - \frac{e^{-\ R_2}}{R_2^3}(1+\gamma R_2) + e^{\gamma a(z+h)}\left[\frac{1}{K_3^3} - \frac{1}{K_4^3}\right]\right\} \tag{9}$$

The constants a and b are determined by:

$a = 0$ and $b = 1$ for $R_2/\delta \ll 1$,

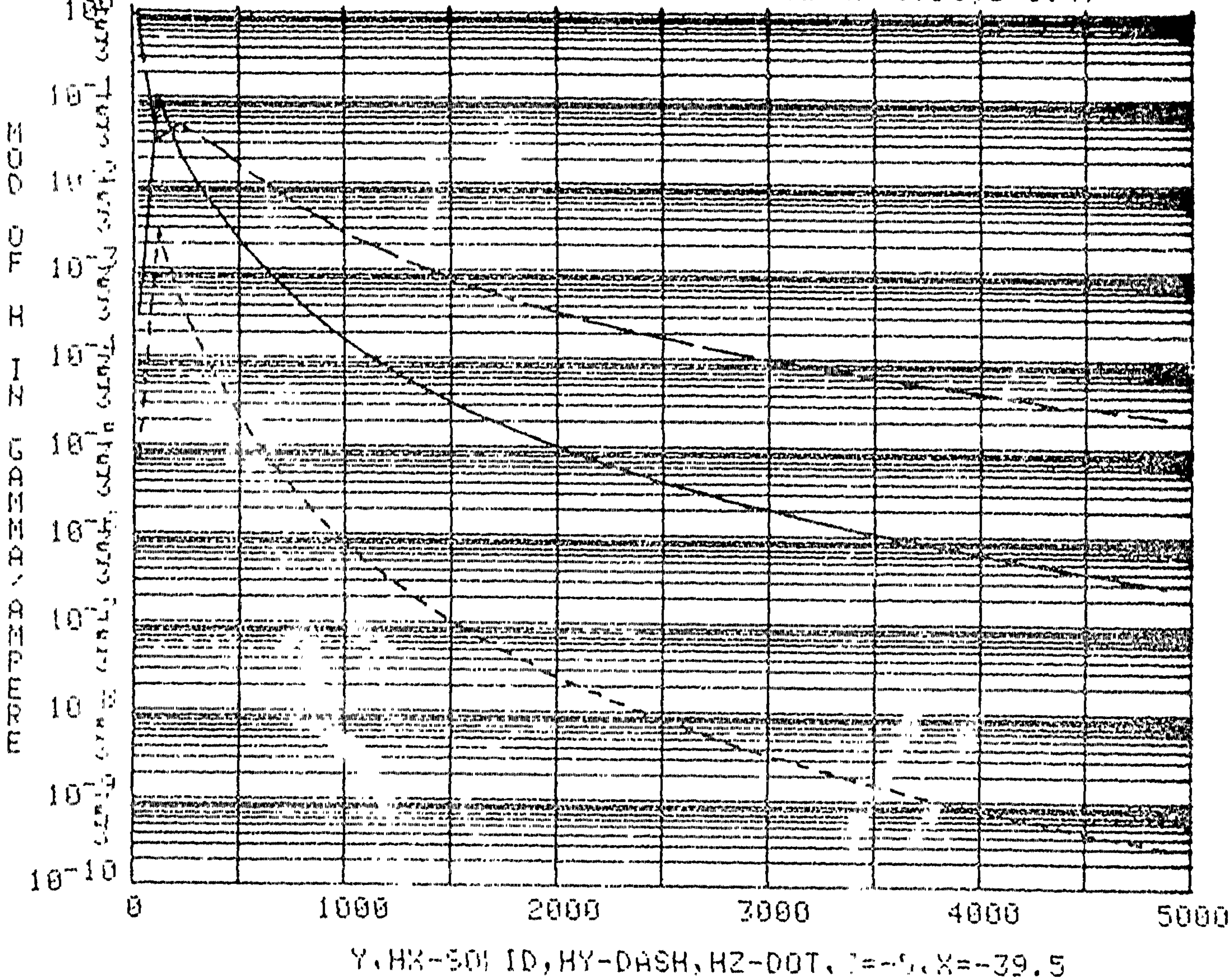
$a = 0.4$ and $b = 0.96$ for R_2/δ less than approximately 1,

$a = 0.96$ and $b = 0.4$ for R_2/δ between approximately 1 and 10,

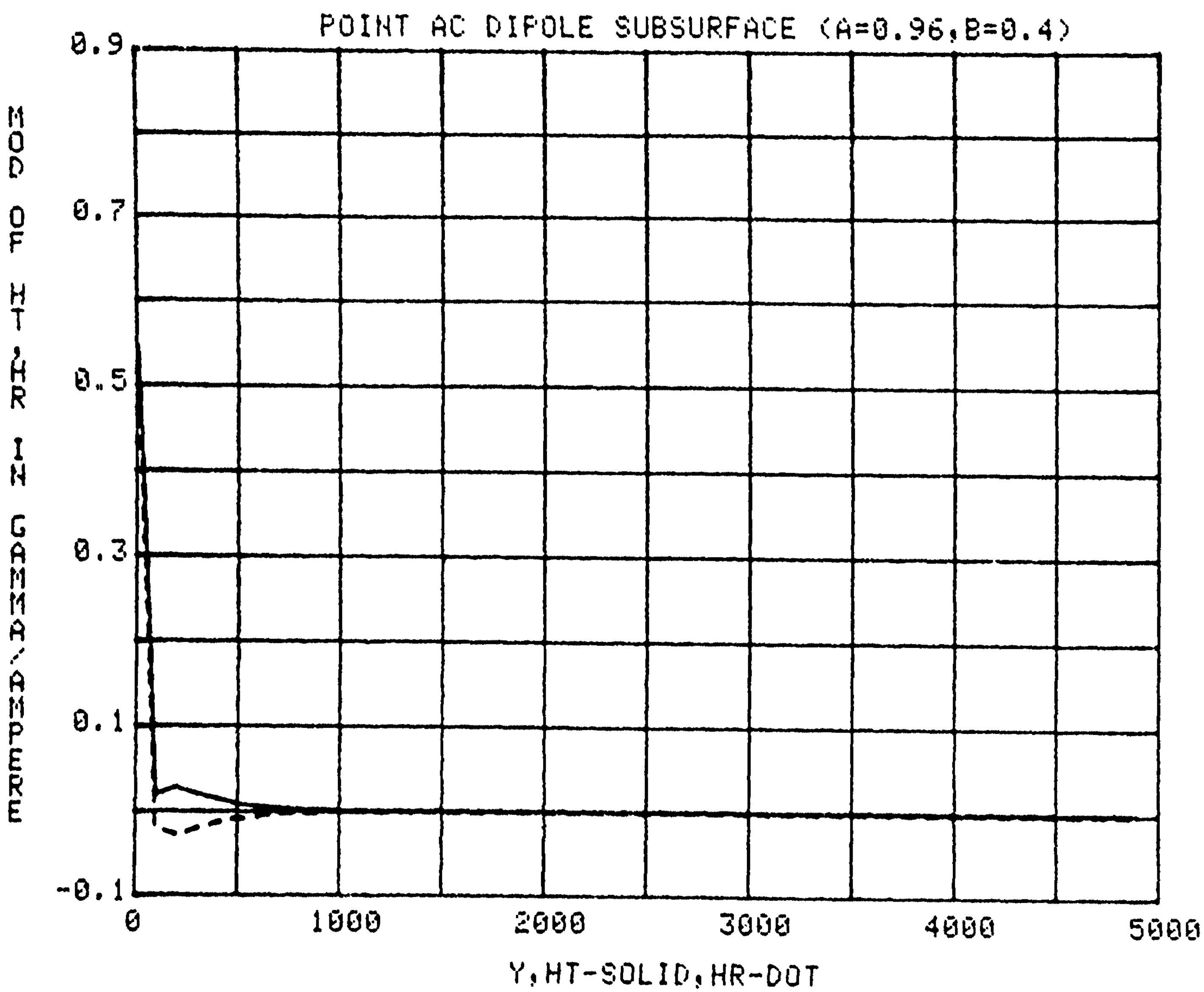
$a = 1$ and $b = 0$ for $\rho > 3|z + h|$.

The name of the program is ACPS (point AC dipole subsurface to subsurface). The sample outputs for this case are shown in Figures 8, 9, and 10. Since this example is for the case where both the dipole and the sensor are subsurface, the value of z is now z = -5m. The path y is once again chosen as $0 < y \leq 5000$m.

POINT AC DIPOLE SUBSURFACE (A=0.96,B=0.4)



?


POINT AC DIPOLE SUBSURFACE (A=0.96,B=0.4)
MOD OF HT,HR IN GAMMA/AMPERE
0.9
0.7
0.5
0.3
0.1
-0.1
0
1000
2000
3000
4000
5000
Y,HT-SOLID,HR-DOT

?

Figure 9

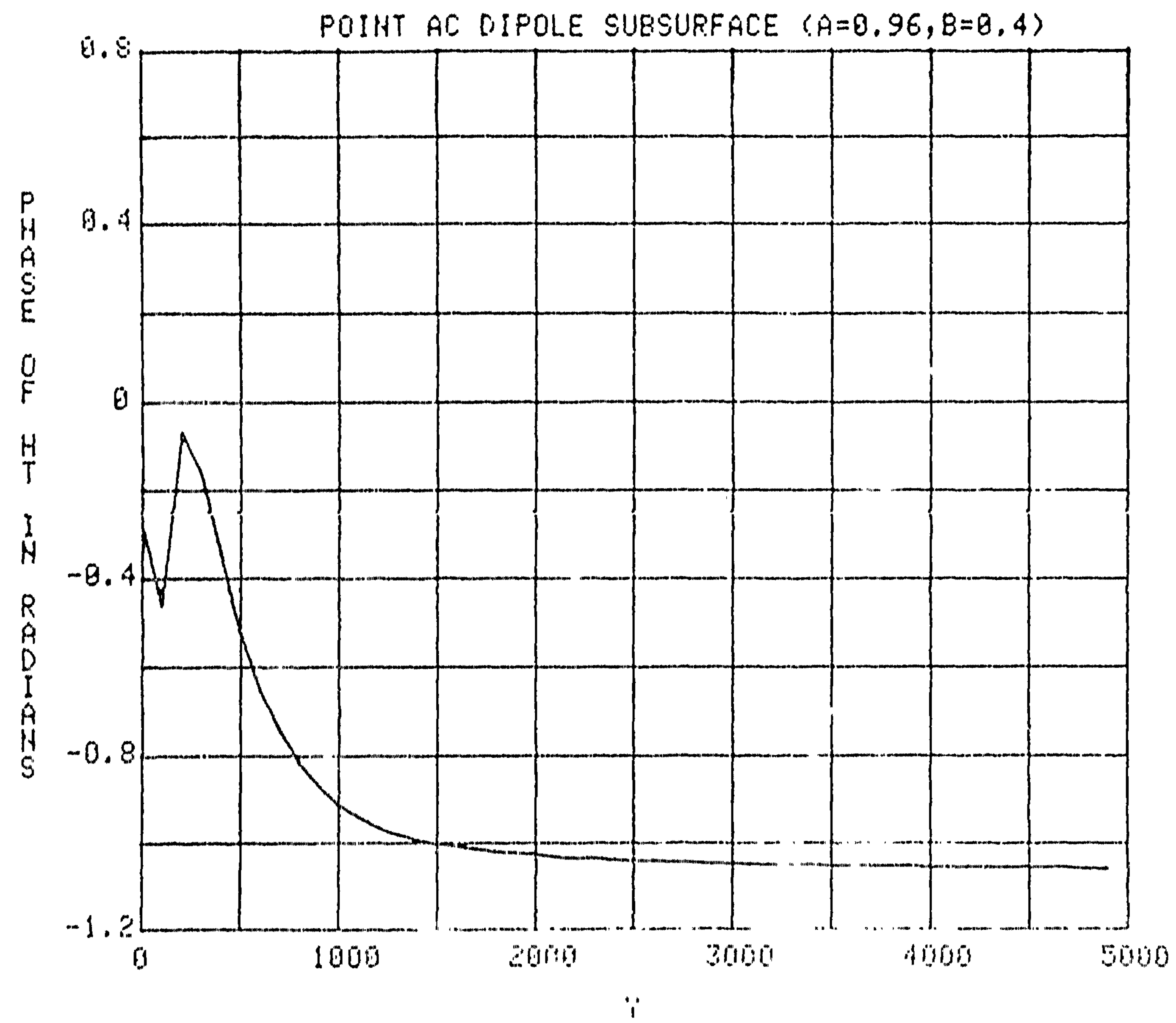

POINT AC DIPOLE SUBSURFACE (A=0.96,B=0.4)
PHASE OF HT IN RADIANS
0.8
0.4
0
-0.4
-0.8
-1.2
0
1000
2000
3000
4000
5000
Y

Figure 16

(D) Point AC dipole subsurface to air propagation in the range $|\gamma R| >> 1$ and $R >> |h|$.

The next three sets of equations (D), (E), and (F) are valid only in restricted ranges.

The expressions for the magnetic field subsurface to air propagation in the range $|\gamma R| >> 1$ and $R >> |h|$ are given, in cylindrical coordinates on page 3-22 of reference 1. In rectangular coordinates, they become:

$$H_x = \frac{3Pxy}{2\pi\gamma} \frac{e^{\gamma h}}{R^3 \rho^2} \left(1 - \frac{z^2}{R^2}\right) \tag{10}$$

$$H_y = \frac{P}{2\pi\gamma} \frac{e^{\gamma h}}{R^3 \rho^2} (2y^2 - x^2 - \frac{3z^2 y^2}{R^2} \tag{11}$$

$$H_z = \frac{3Py}{2\pi\gamma^2} \frac{e^{\gamma h}}{R^5} \left(1 + \gamma z - \frac{5z^2}{R^2}\right) \tag{12}$$

The name of the program for case (D) in ACP1 (Point AC Dipole Subsurface to Air). Figures 11, 12, and 13 are representative outputs of this program.

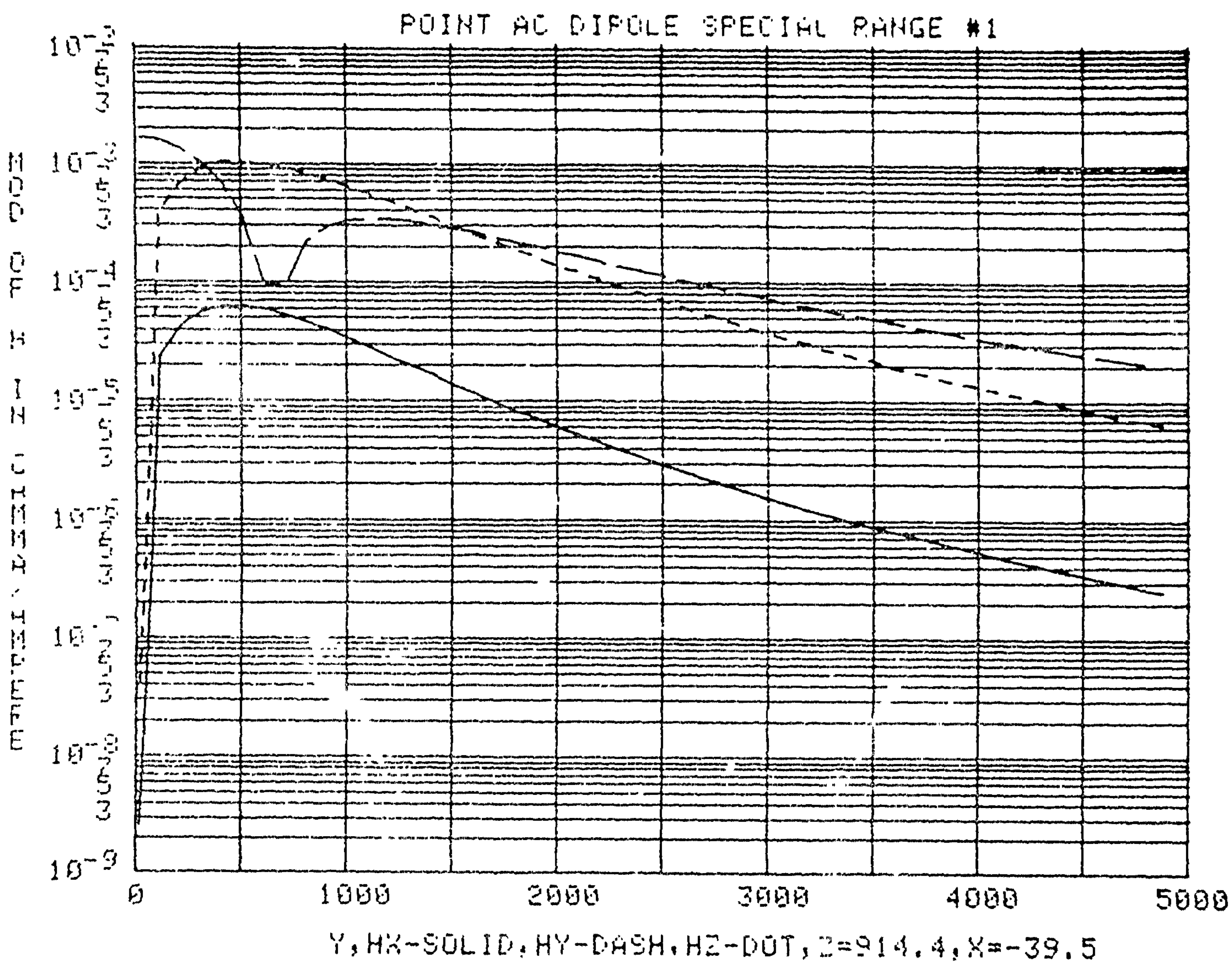

POINT AC DIPOLE SPECIAL RANGE #1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
0
1000
2000
3000
4000
5000
Y,HX-SOLID,HY-DASH,HZ-DOT,Z=914.4,X=-39.5

Figure 11

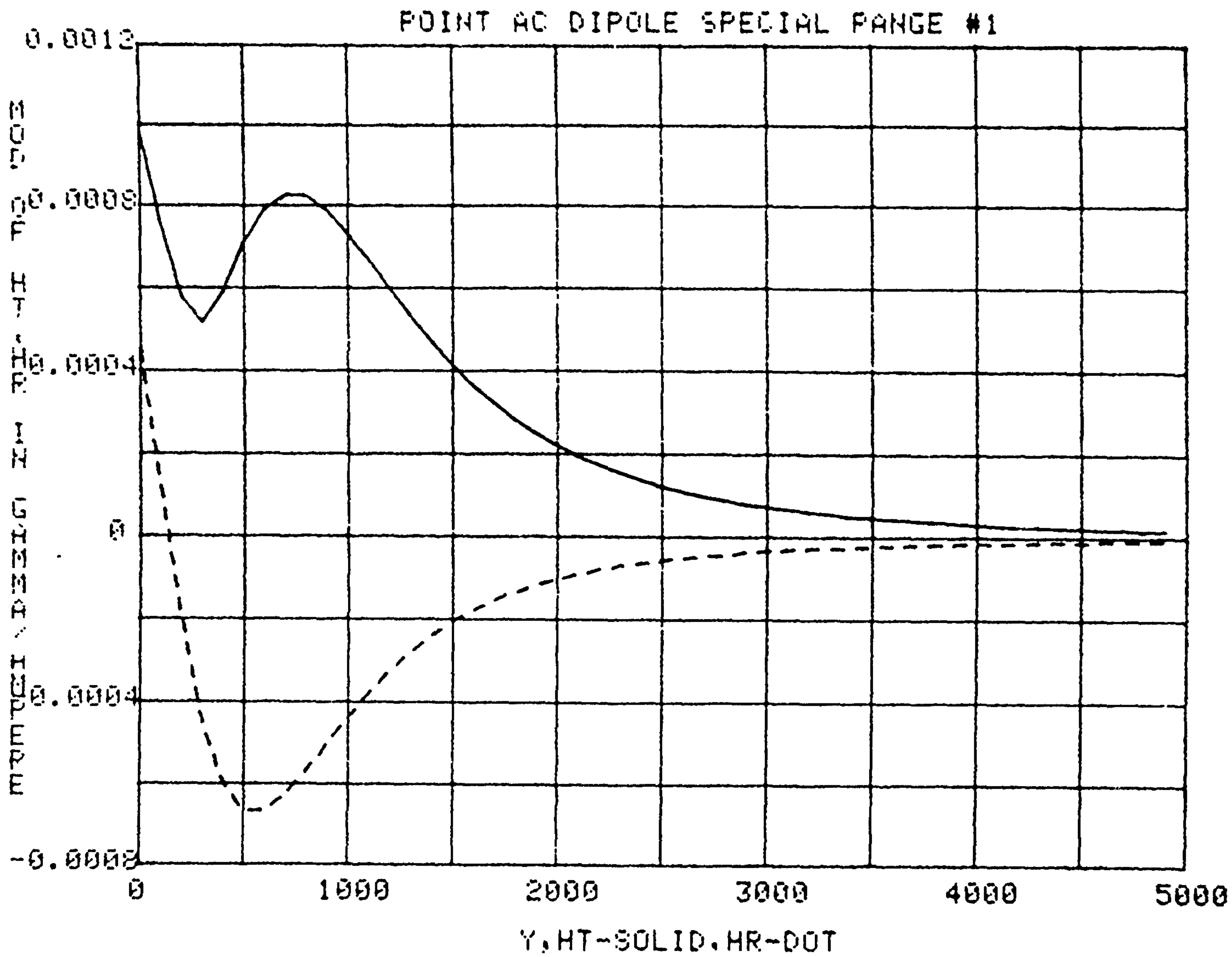

POINT AC DIPOLE SPECIAL RANGE #1
MOD. OF HT.HR IN GAMMA/AMPERE
0.0012
0.0008
0.0004
0
-0.0004
-0.0008
0
1000
2000
3000
4000
5000
Y,HT-SOLID,HR-DOT

Figure 12

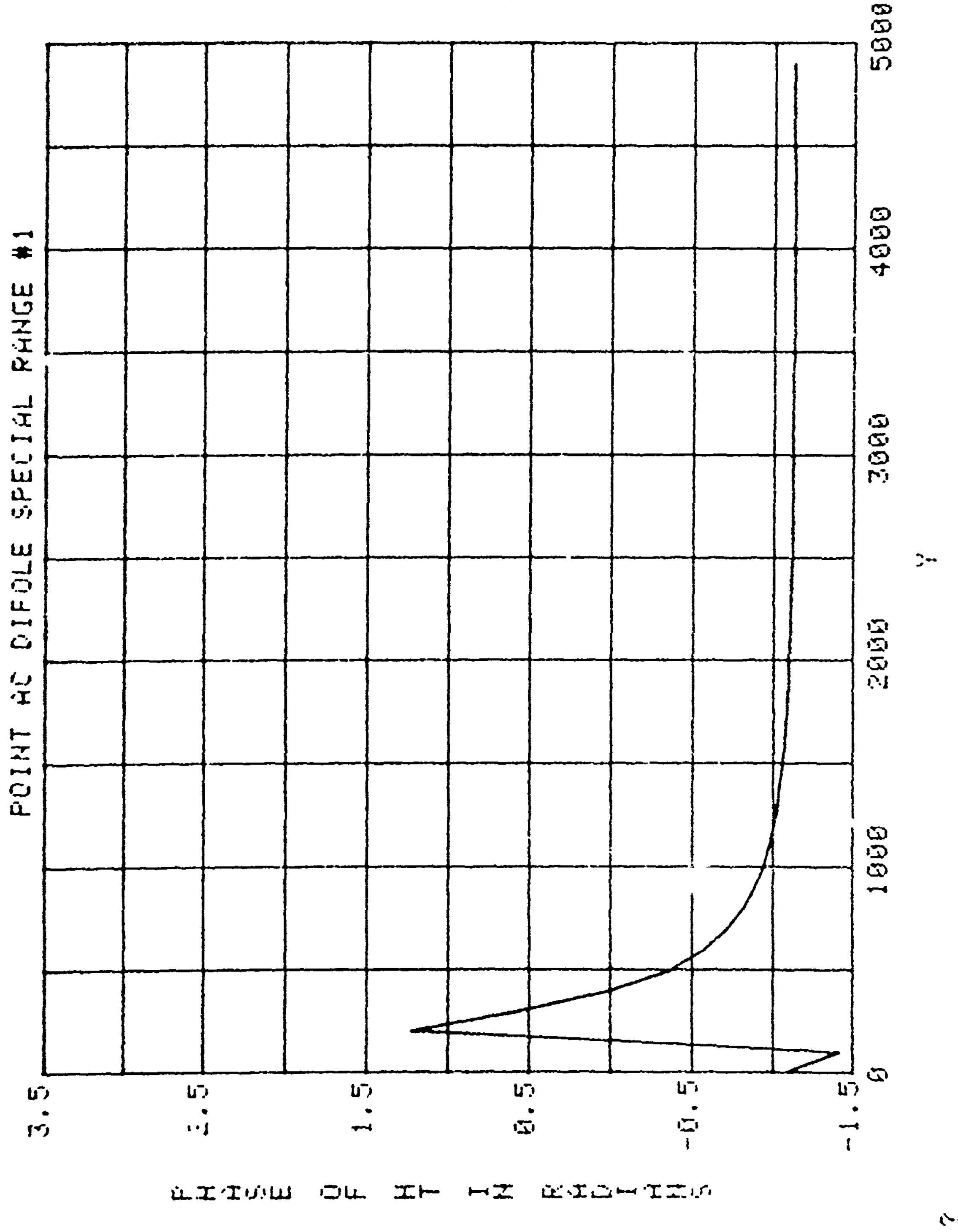

POINT AC DIPOLE SPECIAL RANGE #1
3.5
2.5
1.5
0.5
-0.5
-1.5
0
1000
2000
3000
4000
5000
Y

Figure 13

(E) Point AC dipole subsurface to air propagation in the range $|\gamma\rho|>>1$, $\rho>>|h|$, $\rho>>|z|$.

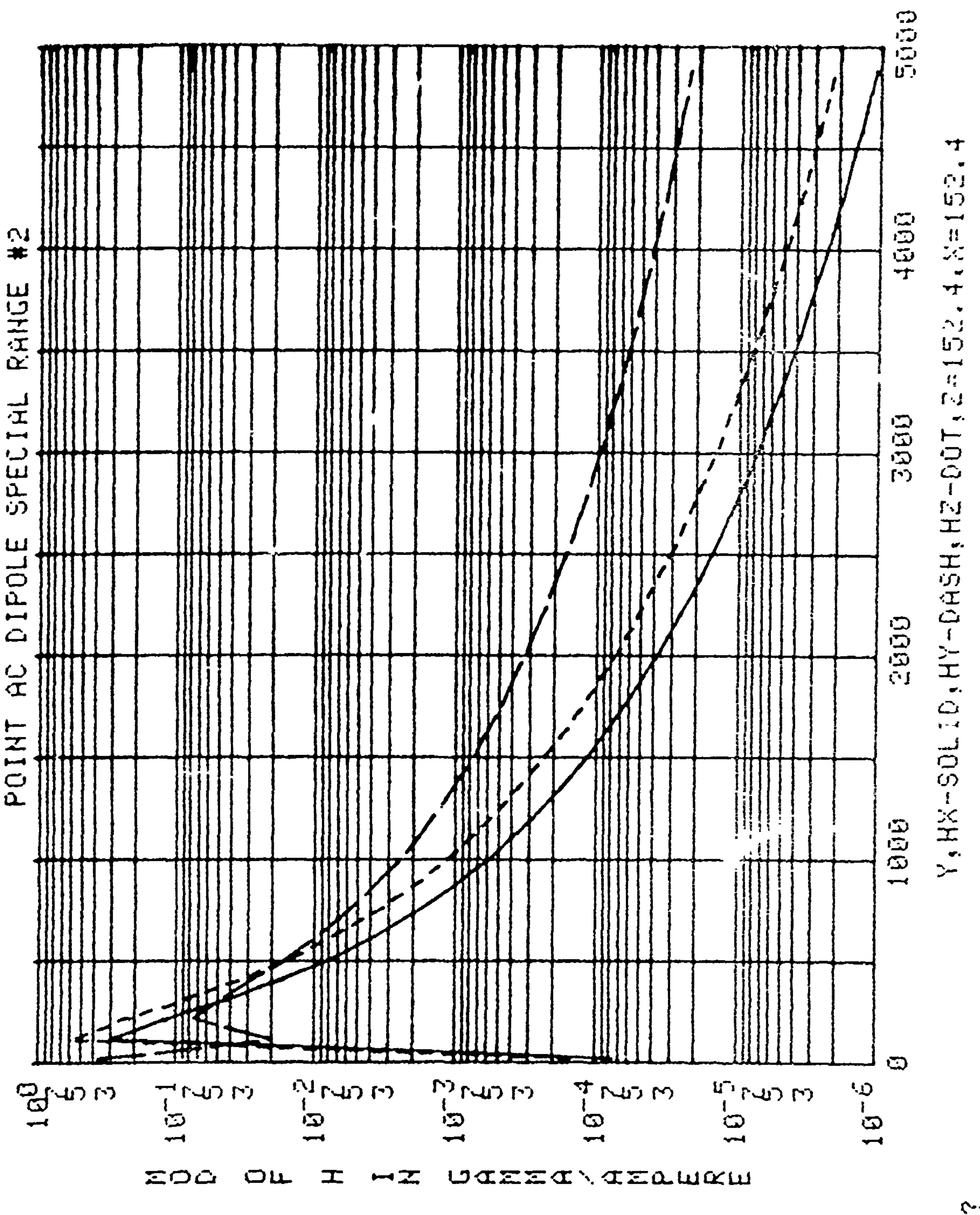
The expressions for the magnetic field subsurface to air propagation in the range $|\gamma\rho|>>1$, $\rho>>|h|$ and $\rho>>|z|$ are given, in cylindrical coordinates, on page 3-24 of reference 1. The expressions are valid only in the vicinity of the z axis. In rectangular coordinates, they become:

$$H_x = \frac{3Pxy}{2\pi\gamma\rho^5} e^{\gamma h} \tag{13}$$

$$H_y = \frac{Pe^{\gamma h}}{2\pi\gamma\rho^5} (2y^2-x^2) \tag{14}$$

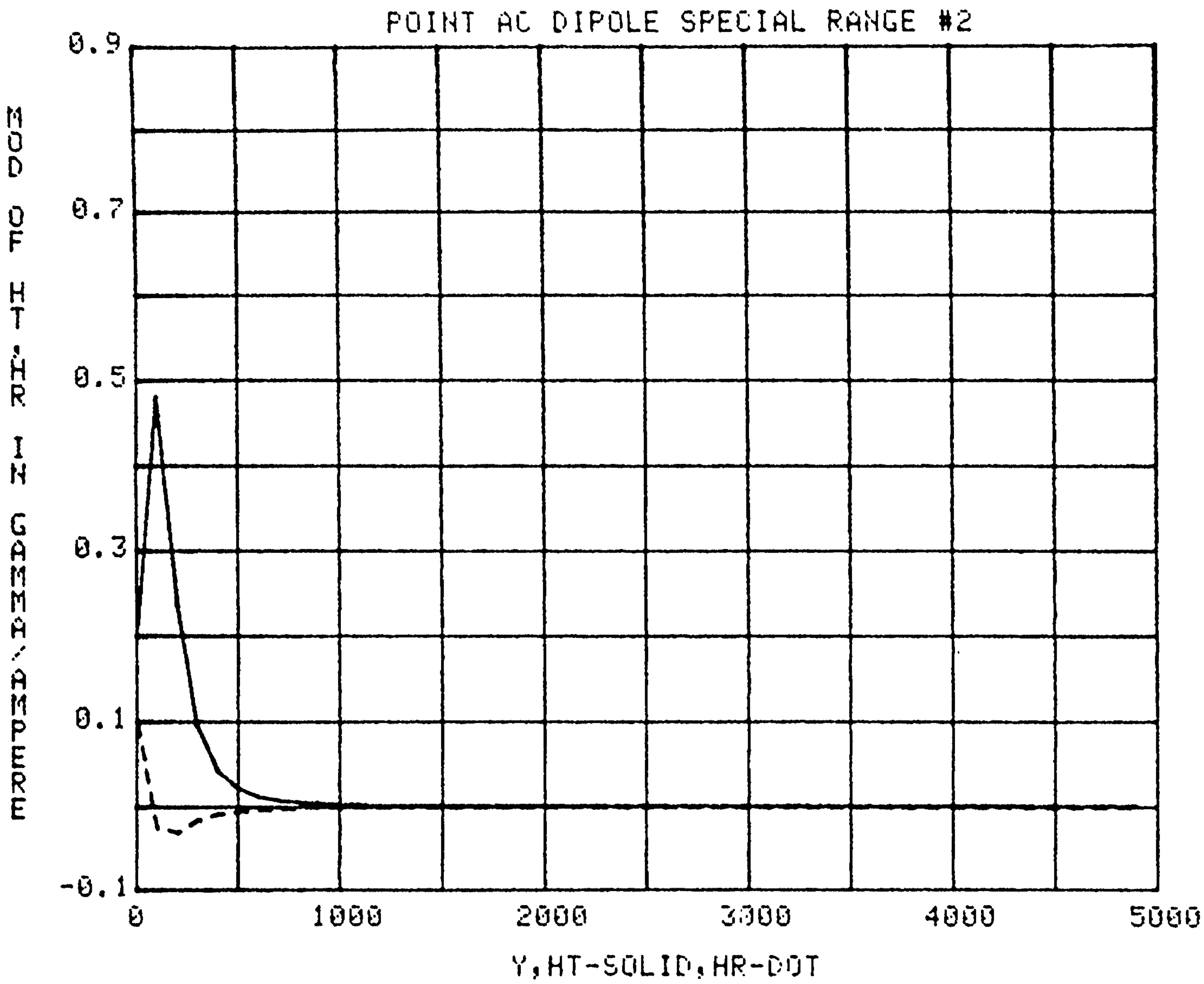
$$H_z = \frac{3Py}{2\pi\gamma^2\rho^5} e^{\gamma h}(1+\gamma z) \tag{15}$$

The program for these equations is named ACP2 (Point AC Dipole Subsurface to Air). Figures 14, 15, and 16 are included as examples. The graphs are plotted along the path x = 152.4m, z = 152.4m, and $0<y\leq 5000$m.



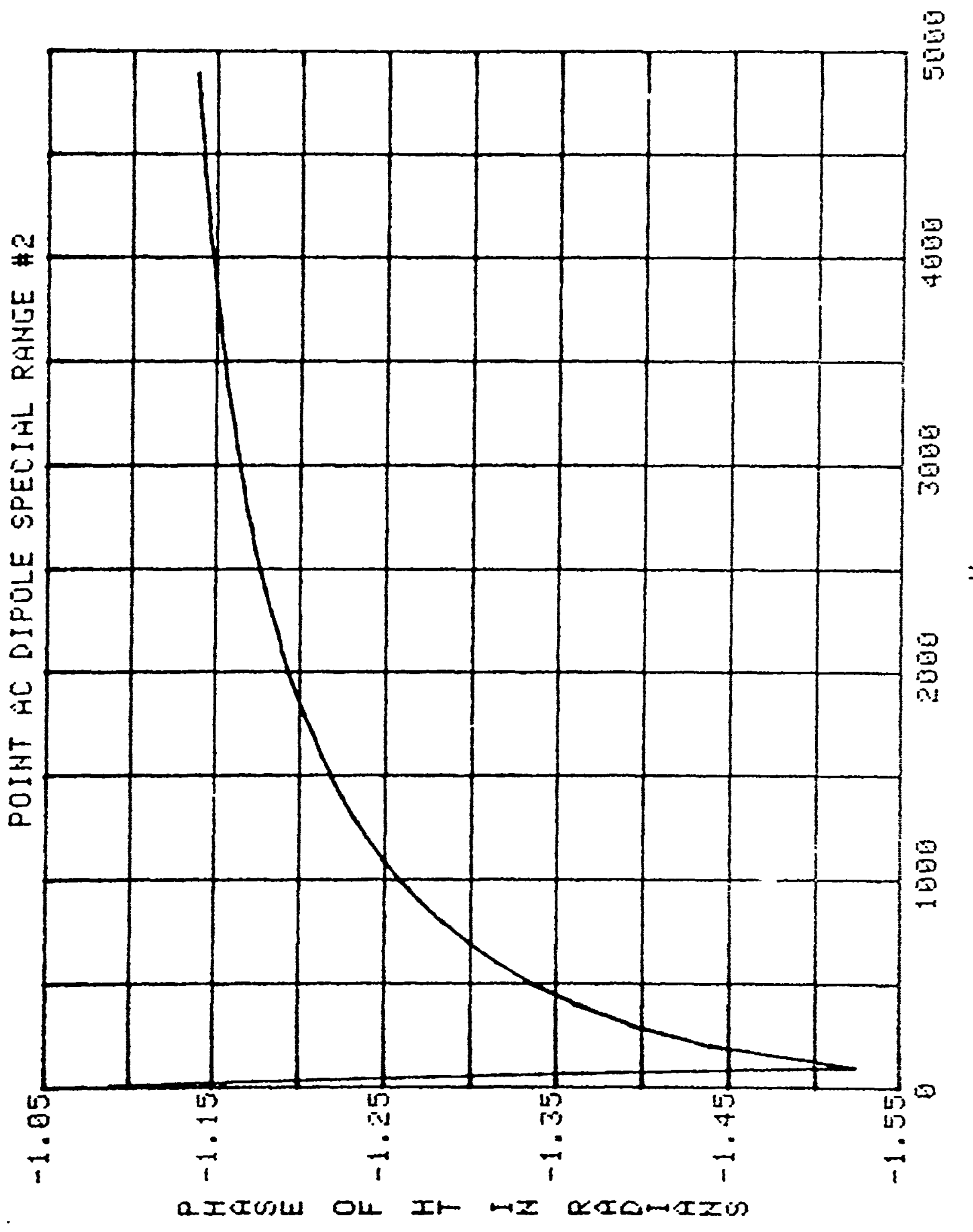
POINT AC DIPOLE SPECIAL RANGE #2
0
1000
2000
3000
4000
5000
Y,HX-SOLID,HY-DASH,HZ-DOT,Z=152.4,X=152.4
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}

Figure 14


POINT AC DIPOLE SPECIAL RANGE #2
0.9
0.7
0.5
0.3
0.1
-0.1
MOD OF HT.HR IN GAMMA/AMPERE
0
1000
2000
3000
4000
5000
Y,HT-SOLID,HR-DOT

?

Figure 15



POINT AC DIPOLE SPECIAL RANGE #2
PHASE OF HT IN RADIANS
Y
-1.05
-1.15
-1.25
-1.35
-1.45
-1.55
0
1000
2000
3000
4000
5000

Figure 16

(F) Point AC dipole subsurface to subsurface propagation in the range $|\gamma\rho|>>1$, $\rho>>|h|$, and $\rho>>|z|$.

The range of this case is identical to that of case (E). The difference lies in the fact that the observation point is in the lower half medium as opposed to the upper half.

The expressions for the magnetic field subsurface to subsurface propagation in the range $|\gamma\rho|>>1$, $\rho>>|h|$, and $\rho>>|z|$ are given, in cylindrical coordinates, on page 3-24 of reference 1. In rectangular coordinates, they become:

$$H_x = \frac{3Pxye^{\gamma(z+h)}}{2\pi\gamma\rho^5} \tag{16}$$

$$H_y = \frac{Pe^{\gamma(z+h)}}{2\pi\gamma\rho^5}\,(2y^2-x^2) \tag{17}$$

$$H_z = \frac{3Py}{2\pi\gamma^2\rho^5}\,e^{\gamma(h+z)} \tag{18}$$

The program for this set of equations has been named ACP2S (Point AC Dipole Subsurface to Subsurface). The sample outputs are shown in Figures 17, 18, and 19. The path of measurement is $x = 152.4$m, $z = -5$m, and $0<y\leq 5000$m.

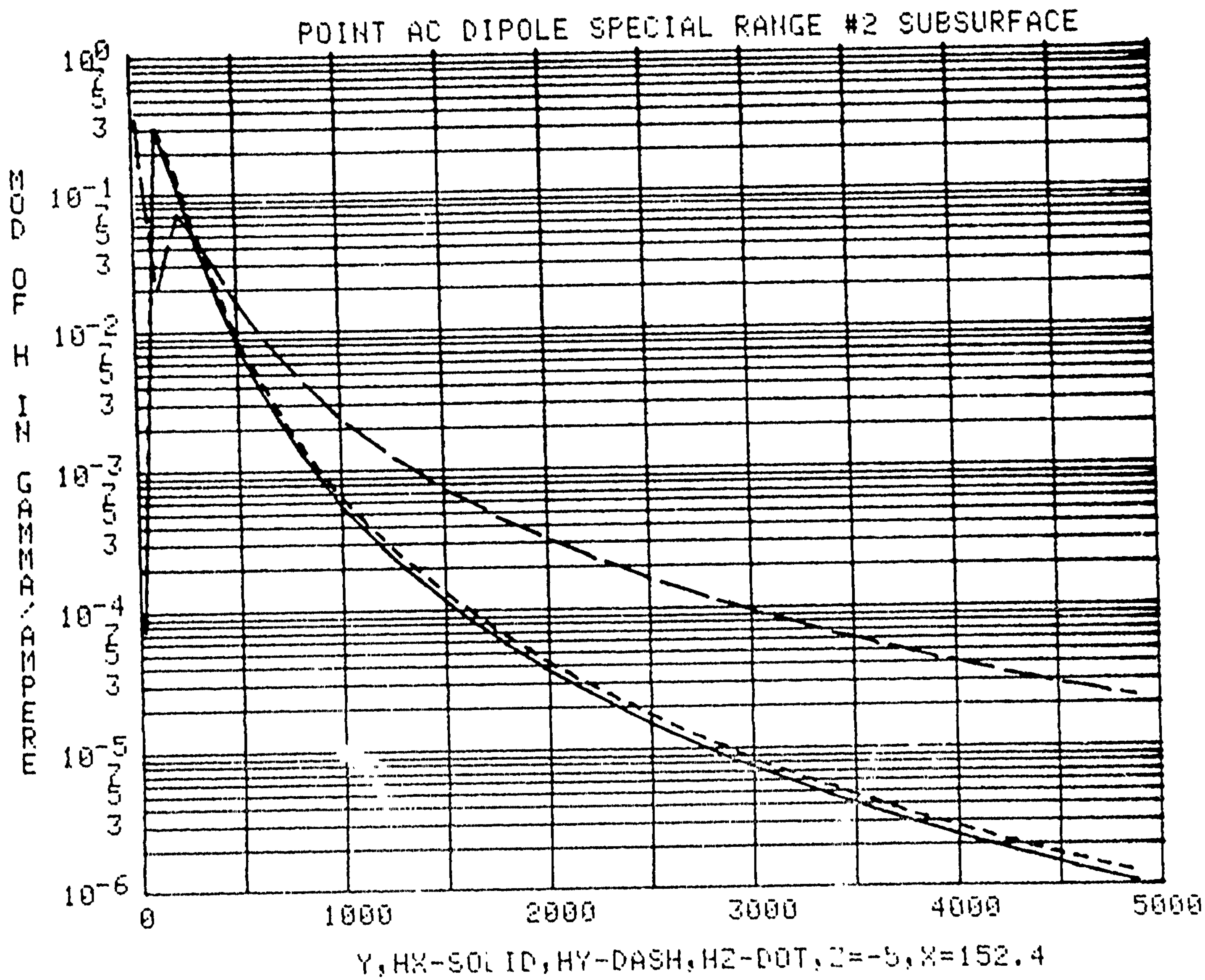

POINT AC DIPOLE SPECIAL RANGE #2 SUBSURFACE
MOD OF H IN GAMMA/AMPERE
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
0
1000
2000
3000
4000
5000
Y,HX-SOLID,HY-DASH,HZ-DOT,Z=-5,X=152.4

Figure 17

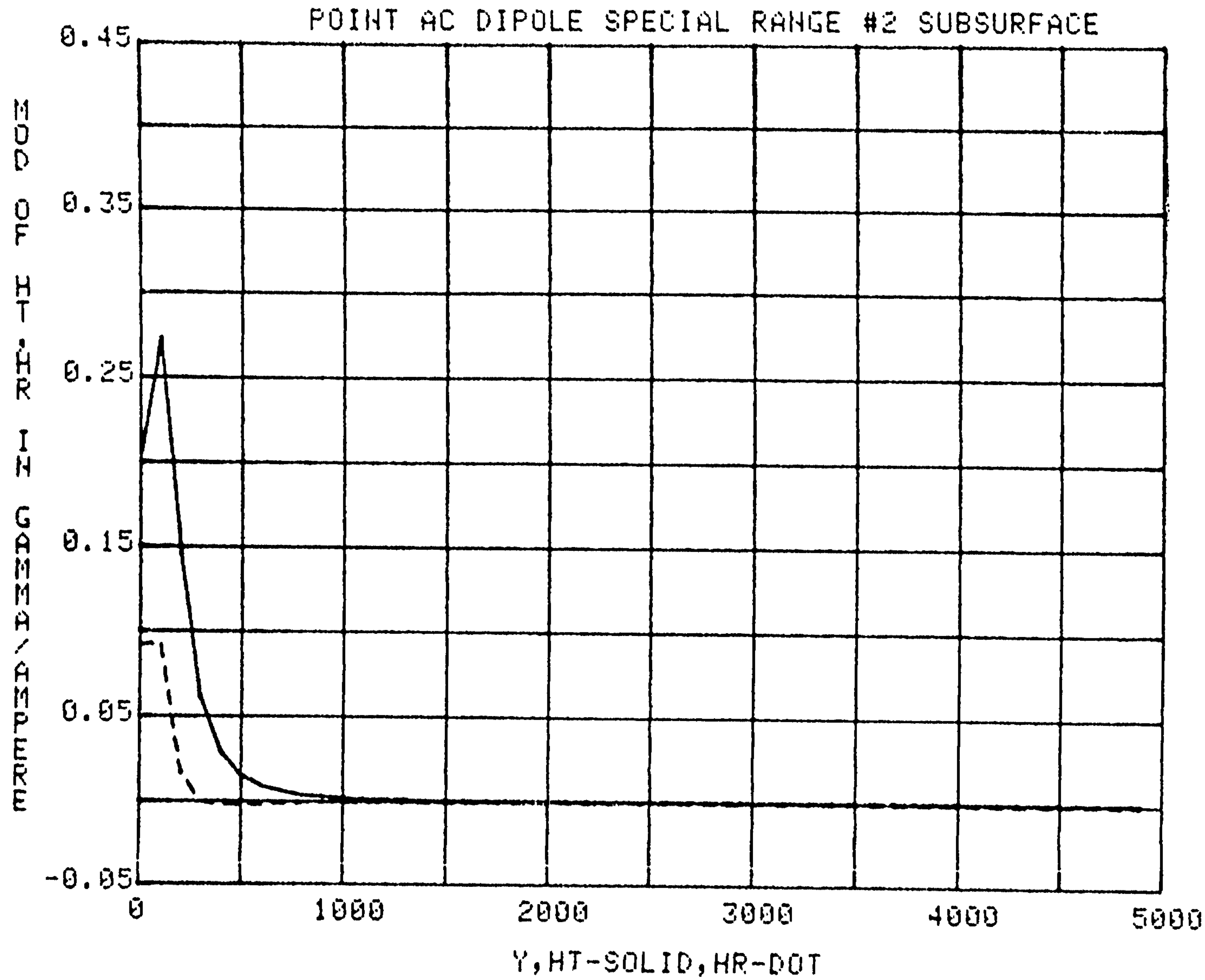

POINT AC DIPOLE SPECIAL RANGE #2 SUBSURFACE
MOD OF HT-HR IN GAMMA/AMPERE
0.45
0.35
0.25
0.15
0.05
-0.05
0
1000
2000
3000
4000
5000
Y,HT-SOLID,HR-DOT

Figure 18

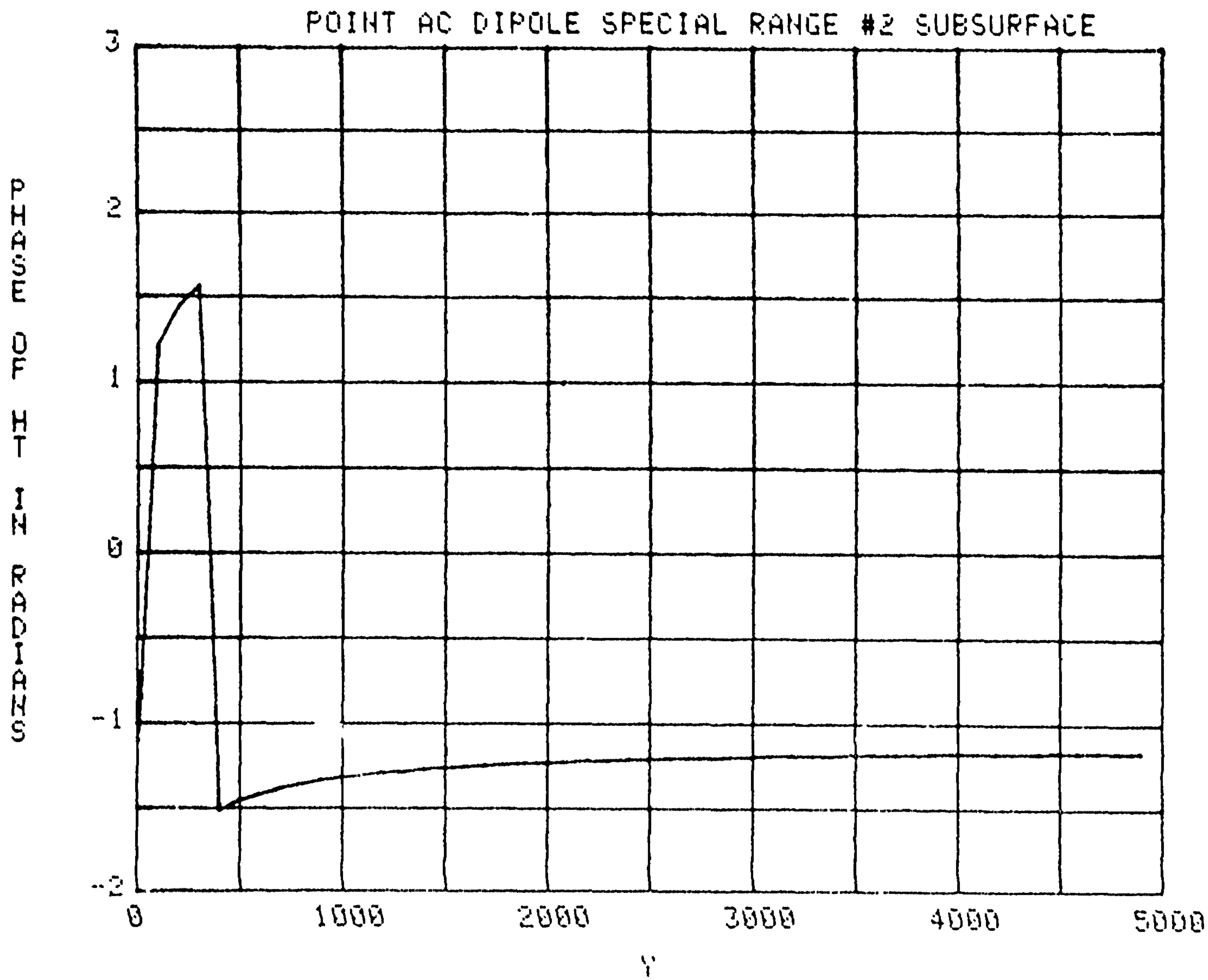

POINT AC DIPOLE SPECIAL RANGE #2 SUBSURFACE
PHASE OF HT IN RADIANS
3
2
1
0
-1
-2
0
1000
2000
3000
4000
5000
Y

Figure 18

(G) Point DC dipole subsurface to air propagation.

The remaining three programs apply to DC sources only. These programs have been used extensively by the David W. Taylor Naval Ship Research and Development Center, Annapolis, Laboratory.

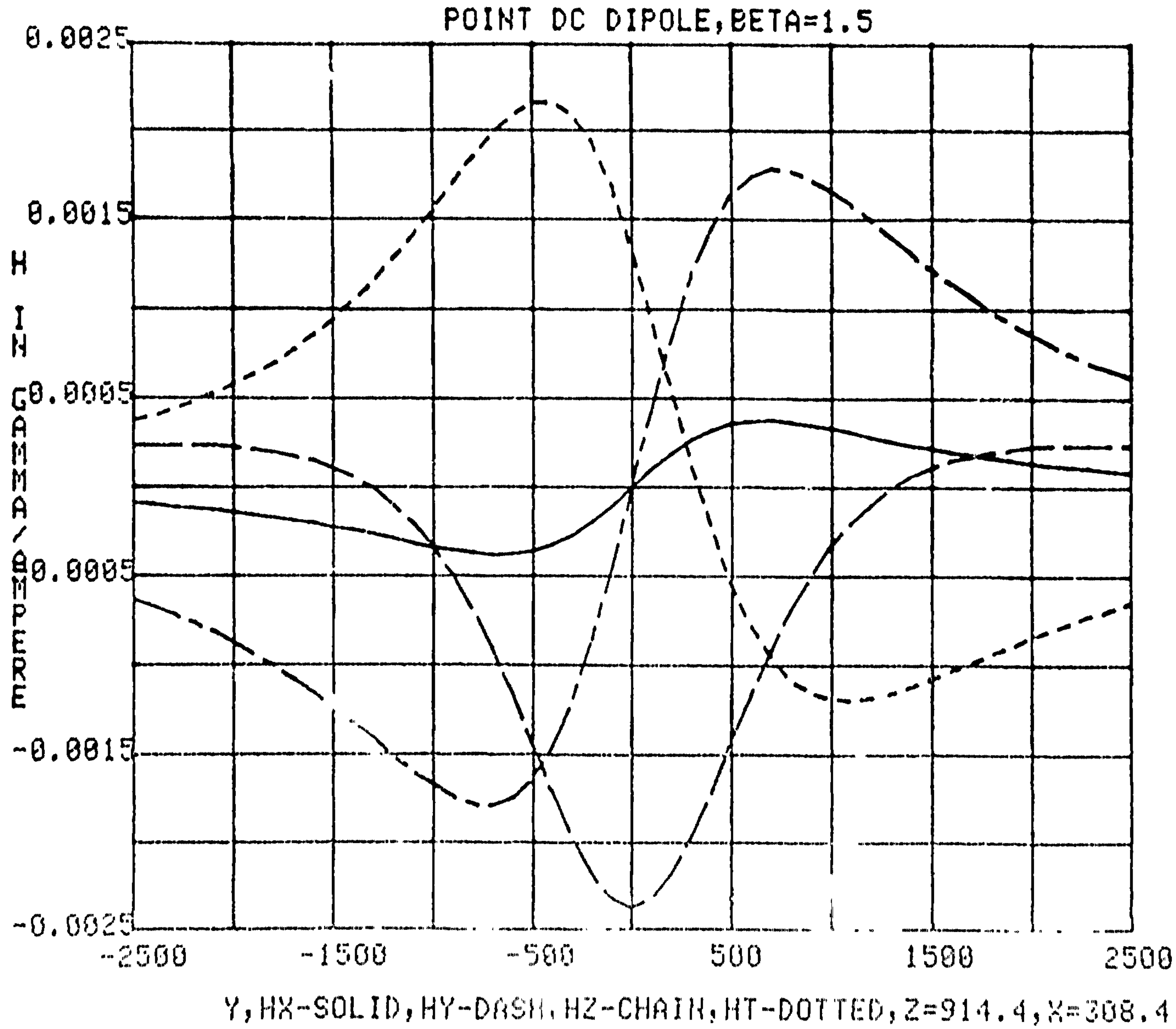
The expressions for the magnetic field subsurface to air propagation due to a point DC dipole are given, in cylindrical coordinates, on page 3-4 of reference 1. In rectangular coordinates, they become:

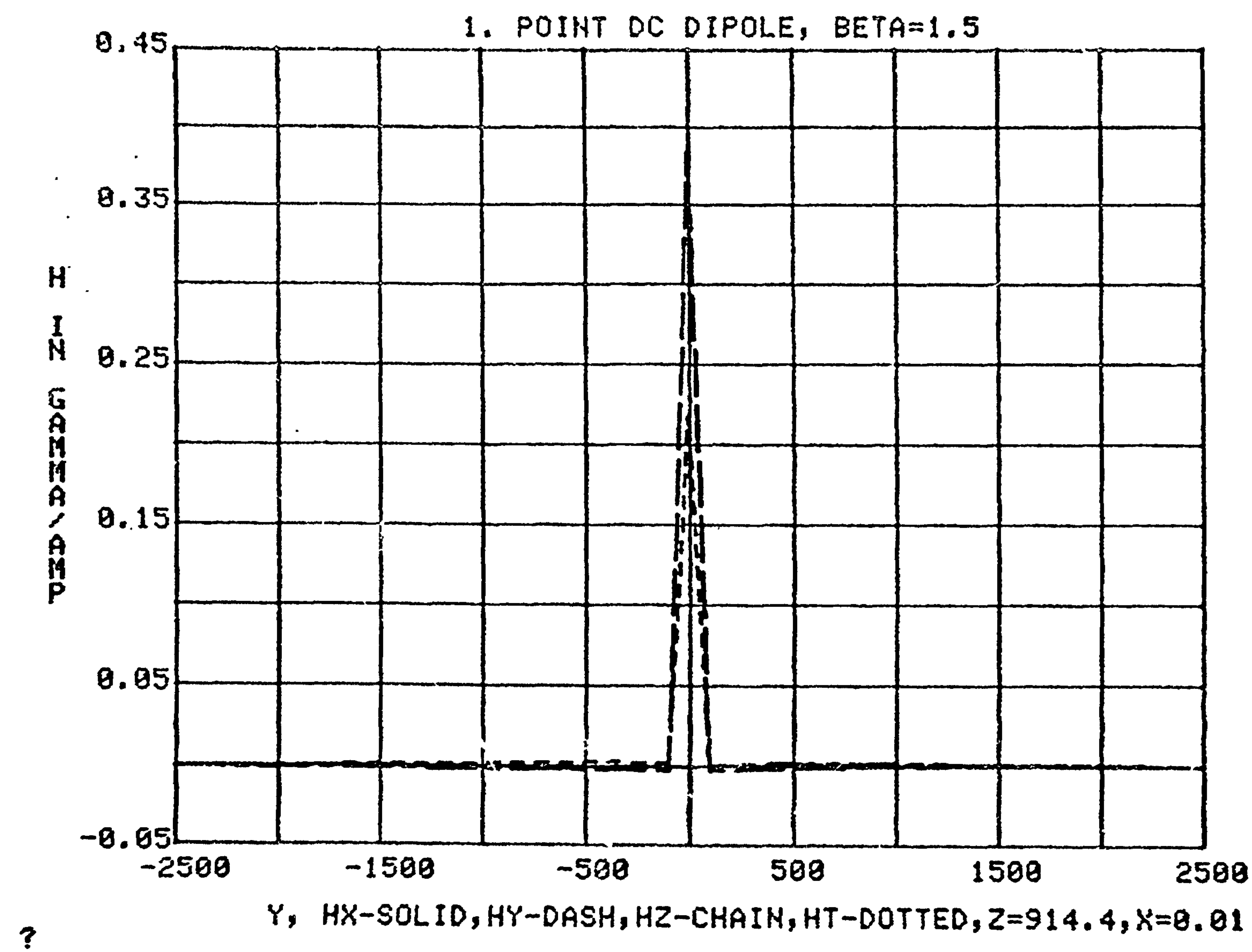
$$H_x = \frac{Pxy}{4\pi\rho^2}\left[\frac{z-h}{R_1^{\,3}} + \frac{2}{\rho^2}\left(\frac{z-h}{R_1} - 1\right)\right] \tag{19}$$

$$H_y = -\frac{P}{4\pi\rho^2}\left[\frac{(z-h)y^2}{R_1^{\,3}} - \frac{x^2-y^2}{\rho^2}\left(\frac{z-h}{R_1} - 1\right)\right] \tag{20}$$

$$H_z = \frac{Py}{4\pi R_1^{\,3}} \tag{21}$$

The program for this set of equations is called DCP (Point DC Dipole Subsurface to Air Propagation). The sample graphs for this case are labeled Figures 20 and 21. The path for Figure 20 is x = 304.8m, z = 914.4m, and $-2500 \leq y \leq 2500$. Since the equation has a singularity at the origin, x was chosen to be 0.01m. The variables z and y are the same for both figures.


POINT DC DIPOLE,BETA=1.5
0.0025
0.0015
0.0005
-0.0005
-0.0015
-0.0025
H IN GAMMA/AMPERE
-2500
-1500
-500
500
1500
2500
Y,HX-SOLID,HY-DASH,HZ-CHAIN,HT-DOTTED,Z=914.4,X=308.4



1. POINT DC DIPOLE, BETA=1.5
H IN GAMMA/AMP
0.45
0.35
0.25
0.15
0.05
-0.05
-2500
-1500
-500
500
1500
2500
Y, HX-SOLID,HY-DASH,HZ-CHAIN,HT-DOTTED,Z=914.4,X=0.01

Figure 21

(H) Finite length DC dipole subsurface to air propagation.

The magnetic field expressions (1), (2), and (3) for a finite length AC dipole can be used to derive the corresponding DC expressions. As $d\to\infty$, $e^{\gamma ah}\to 1$, and $b = 1$, we have:

$$\frac{d+z-bh}{K_{12}}\to 1, \qquad \frac{d+z-bh}{K_{11}}\to 1,$$

$$\frac{1}{K_{11}}\to 0, \qquad \frac{1}{K_{12}}\to 0.$$

and equations (1), (2), and (3) reduce to:

$$H_x = \frac{Iy}{4\pi}\left[\frac{1}{(x-\frac{L}{2})^2+y^2}\left(1-\frac{z-h}{K_{22}}\right) - \frac{1}{(x+\frac{L}{2})^2+y^2}\left(1-\frac{z-h}{K_{22}}\right)\right] \tag{22}$$

$$H_y = \frac{I}{4\pi}\left[\frac{z-h}{y^2+(z-h)^2}\left(\frac{x+\frac{L}{2}}{K_{21}} - \frac{x-\frac{L}{2}}{K_{22}}\right) - \frac{x+\frac{L}{2}}{y^2+(x+\frac{L}{2})^2}\left(1-\frac{z-h}{K_{21}}\right)\right] \tag{23}$$

$$H_z = \frac{Iy}{4\pi}\,\frac{1}{y^2+(z-h)^2}\left(\frac{x+\frac{L}{2}}{K_{21}} - \frac{x-\frac{L}{2}}{K_{22}}\right) \tag{24}$$

Equations (22), (23), and (24) give the magnetic field components for a finite length DC dipole. When the finite length L is much less than the measurement distance, we have:

$$\frac{1}{K_{21}}\to\frac{1}{R_1}\left(1-\frac{xL}{2R_1^2}\right), \qquad \frac{1}{K_{22}}\to\frac{1}{R_1}\left(1-\frac{xL}{2R_1^2}\right),$$

$$\frac{1}{(x-\frac{L}{2})^2+y^2}\to\frac{1}{\rho^2}\left(1+\frac{xL}{\rho^2}\right), \qquad \frac{1}{(x+\frac{L}{2})^2+y^2}\to\frac{1}{\rho^2}\left(1-\frac{xL}{\rho^2}\right)$$

and $IL \to P$.

Consequently, equations (22), (23), and (24) reduce, respectively, to the point dipole equations (19), (20), and (21).

The name of the program for this set of equations is DCF (Finite Length DC Dipole Subsurface to Air).

Figure 22 shows the magnetic fields due to a DC dipole of length 50m, located at a depth of 76.2m, for the path z = 914.4m, x = 304.8m, and $-2500m \leq y \leq 2500m$. The earth's magnetic field direction in the xy-plane forms an angle of 1.5π radium relative to the x axis. Figure 23 gives the corresponding curve for a point DC dipole. Figure 22 and Figure 23 show that along this path, the finite length dipole results are in very good agreement with corresponding point dipole results. The point dipole equations (19), (20), and (21) have a singularity at the origin. Therefore, they are not valid near the z axis. Figures (21) and (23) point out the discrepancy encountered when the observation path is near the z axis. Both figures are measured at the same height, z = 914.4m, and y is bounded by, $-2500 \leq y \leq 2500$. Even though the values for x are very close to each other, 0.00m and 0.01m, the magnetic field strengths appear to be vastly different near the z axis.

The finite dipole equations (22), (23), and (24) predict magnetic fields close to that predicted by the point dipole equations when the observation points are away from the origin. In addition, they do not have a singularity at the origin.

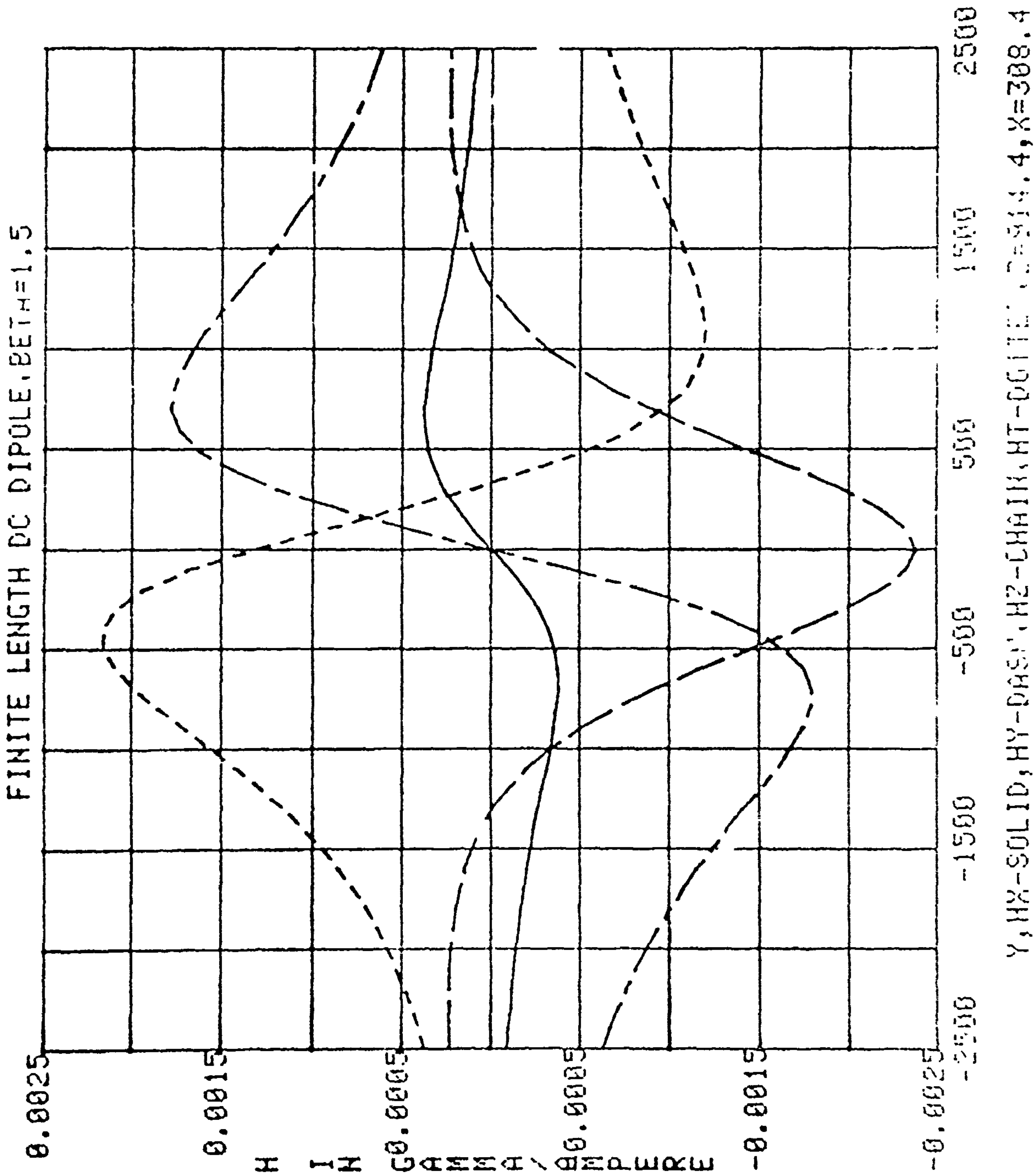
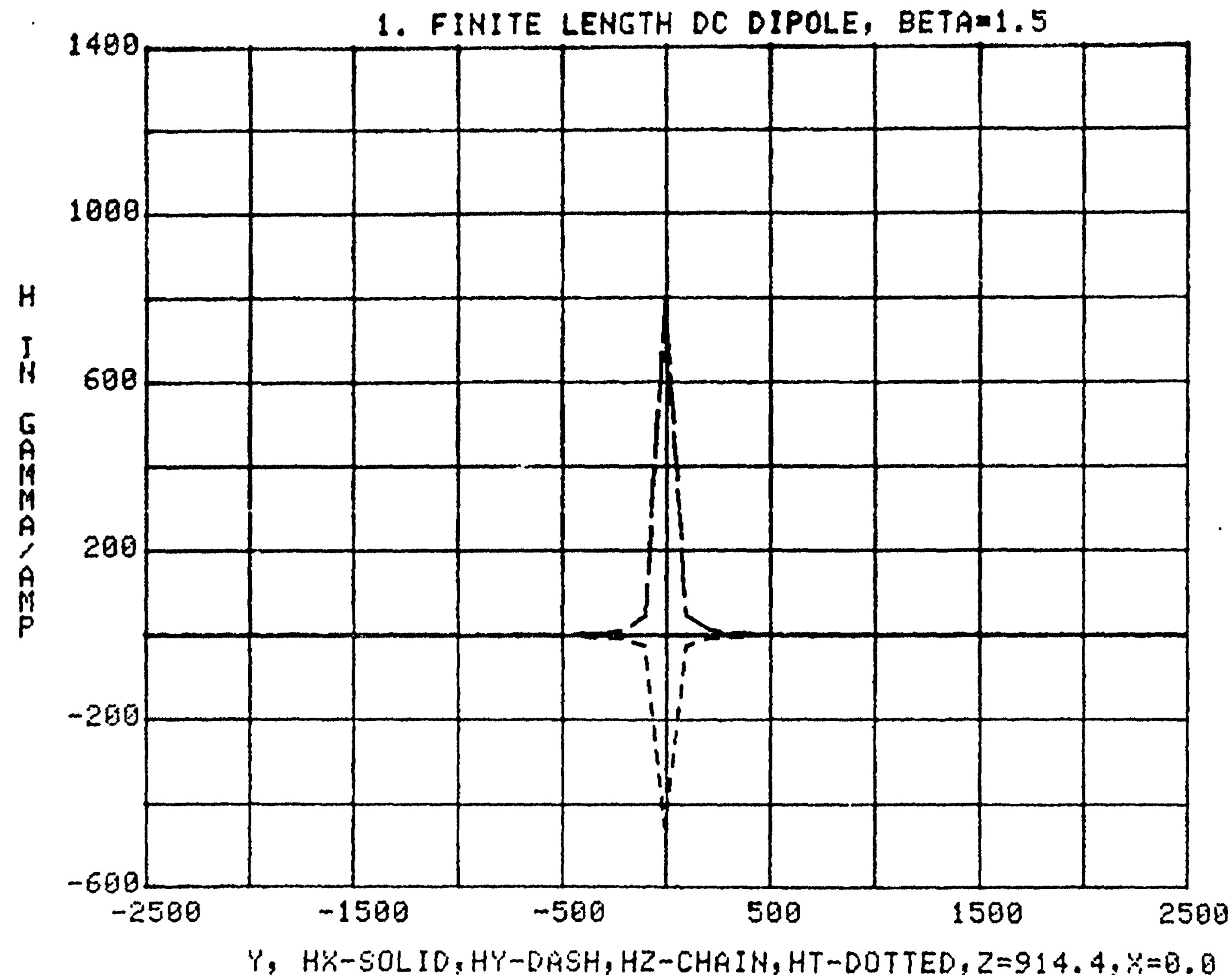

FINITE LENGTH DC DIPOLE,BETA=1.5
0.0025
0.0015
0.0005
-0.0005
-0.0015
-0.0025
-2500
-1500
-500
500
1500
2500

Figure 22


1. FINITE LENGTH DC DIPOLE, BETA=1.5
1400
1000
600
200
-200
-600
H IN GAMMA/AMP
-2500
-1500
-500
500
1500
2500
Y, HX-SOLID,HY-DASH,HZ-CHAIN,HT-DOTTED,Z=914.4,X=0.0

?

Figure 23

(I) Point DC dipole subsurface to subsurface propagation.

The expressions for the magnetic field subsurface to subsurface propagation due to a point DC dipole are given, in cylindrical coordinates, on page 3-4 of reference 1. In rectangular coordinates, they become:

$$H_x = \frac{Pxy}{4\pi\rho^2}\left[\frac{z+h}{R_2^3} + \frac{2}{\rho^2}\left(\frac{z+h}{R_2} + 1\right)\right] \tag{25}$$

$$H_y = -\frac{P}{4\pi}\left[\frac{z-h}{R_1^3} + \frac{x^2(z+h)}{\rho^2 R_2^3} + \frac{x^2-y^2}{\rho^4}\left(\frac{z+h}{R_2} + 1\right)\right] \tag{26}$$

$$H_z = \frac{Py}{4\pi R_1^3} \tag{27}$$

The name of the program is DCPS (Point DC Dipole Subsurface to Subsurface). The appropriate graph is given in Figure 24. The path of measurement is $z = -5$m, $x = -39.5$m, and $0 \le y \le 5000$m.

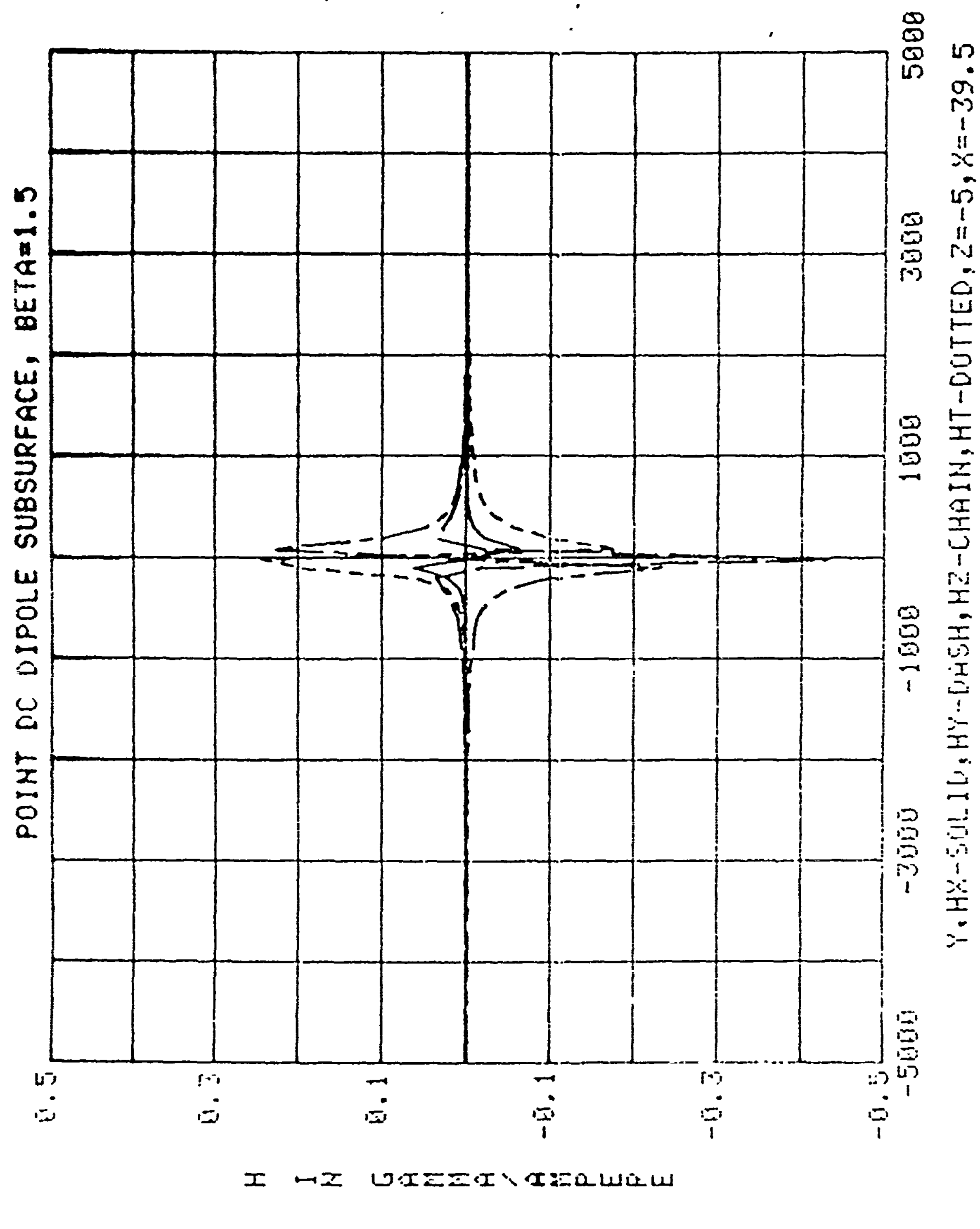

POINT DC DIPOLE SUBSURFACE, BETA=1.5
0.5
0.3
0.1
-0.1
-0.3
-0.5
-5000
-3000
-1000
1000
3000
5000
Y,HX-SOLID,HY-DASH,HZ-CHAIN,HT-DOTTED,Z=-5,X=-39.5

Figure 24

DISCUSSION

The computer programs can be used to find the magnetic fields along certain chosen paths in the upper half or in the lower half medium. The corresponding magnetic curves for each path can then be plotted. The systems which predict the results for DC sources have been utilized extensively by the David W. Taylor Naval Ship Research and Development Center, Annapolis, Maryland.

APPENDIX I

Operating Instructions and Program Listings

OPERATING INSTRUCTIONS

The programs are intended to be run in an interactive mode. Data which is required for each individual program is requested by the program at run time. Depending on the particular program which is being run, the user will be required to furnish the values of some combination of the following parameters:

(a) The height of the measurement path, that is, the value of z.

(b) The values for the constants a and b, required when using Modified Image Theory.

(c) The range of the y value of the measurement path and the increment along that path.

(d) The angle of the earth's magnetic field direction. The angle is assumed to be in K π radians, but the user need only provide the value for K.

The output of the programs is stored in data files. Each AC program writes into three files; one for H_x, H_y and H_z; one for H_t and H_r; and the third is used to store the phase. Each DC program requires only one output file. H_x, H_y, H_z and H_t are all stored in this file. These files may now provide input to TEKGRAF2, a graphics plotting package developed at the United States Naval Academy. Reference 3 provides operating instructions for this package.

REFERENCES

1. Kraichman, M. C., Handbook of Electromagnetic Propagation in Conducting Media, U. S. Government Printing Office, Washington, D. C., Second Edition, 1976.

2. Bannister, P. R. and Dube, R. L., Modified Image Theory Quasi-static Range Subsurface-to-Subsurface and Subsurface-to-Air Propagation Equations, NUSC Technical Report 5647, 1977.

3. Bannister, Peter R., et al, Scientific and Engineering Studies - Quasi-static Electromagnetic Fields, Naval Underwater Systems Center.

4. Richardson, J. Douglas, User Documentation for the "L.IF***:TEKGRAF2" Plotting Package, CADIG, USNA, 1978.

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Annapolis Laboratory
Annapolis, Maryland 21402
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ACF

```
 *     MODIFIED IMAGE THEORY FOR FINITE LENGTH AC SUB TO AIR
 *     NUSC REPORT 5647
       COMPLEX FUNCTION HX(FREQ,X,Y,Z)
       COMPLEX ZDB,ZDBY,K11,K12
       COMPLEX COEFF,GAMMA
       REAL K21,K22
       REAL LENGTH
       COMMON DEPTH,LENGTH,CURENT,ACON,BCON,PI
       GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
       XLP = X + LENGTH/2
       XLM = X - LENGTH/2
       ZB = Z -BCON*DEPTH
       ZDB = Z + 2/GAMMA - BCON*DEPTH
       XLPY = XLP**2 + Y**2
       XLMY = XLM**2 + Y**2
       ZDBY = ZDB**2 + Y**2
       ZBY = ZB**2 + Y**2
       K11 = CSQRT(XLP**2 + ZDBY)
       K12 = CSQRT(XLM**2 + ZDBY)
       K21 = SQRT(XLP**2 + ZBY)
       K22 = SQRT(XLM**2 + ZBY)
       COEFF = Y*CURENT * CEXP(GAMMA*ACON*DEPTH)
 1     HX = 100.*COEFF*((ZDB/K12 - ZB/K22)/XLMY - (ZDB/K11 - ZB/K21)/XLPY)
       RETURN
       END
       COMPLEX FUNCTION HY(FREQ,X,Y,Z)
       COMPLEX ZDB,ZDBY,K11,K12
       COMPLEX HY1,HY3,HY4,GAMMA,YCOEFF
       REAL K21,K22
       REAL LENGTH
       COMMON DEPTH,LENGTH,CURENT,ACON,BCON,PI
       GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
       XLP = X + LENGTH/2
       XLM = X - LENGTH/2
       ZB = Z -BCON*DEPTH
       ZDB = Z + 2/GAMMA - BCON*DEPTH
       XLPY = XLP**2 + Y**2
       XLMY = XLM**2 + Y**2
       ZDBY = ZDB**2 + Y**2
       ZBY = ZB**2 + Y**2
       K11 = CSQRT(XLP**2 + ZDBY)
       K12 = CSQRT(XLM**2 + ZDBY)
       K21 = SQRT(XLP**2 + ZBY)
       K22 = SQRT(XLM**2 + ZBY)
       YCOEFF = CURENT * CEXP(GAMMA*ACON*DEPTH)
 2     HY1 = (XLP/K11 - XLM/K12)*ZDB/ZDBY
       HY2 = (XLP/K21 - XLM/K22)*ZB/ZBY
       HY3 = (ZDB/K11 - ZB/K21)*XLP/XLPY
       HY4 = (ZDB/K12 - ZB/K22)*XLM/XLMY
       HY = 100.*YCOEFF*(HY1-HY2+HY3-HY4)
       RETURN
       END
```

07/21/80 13:51:44

```
      COMPLEX FUNCTION HZ(FREQ,X,Y,Z)
      COMPLEX ZDB,ZDBY,K11,K12
      COMPLEX GAMMA,COEFF
      REAL K21,K22
      REAL LENGTH
      COMMON DEPTH,LENGTH,CURENT,ACON,BCON,PI
      GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
      XLP = X + LENGTH/2
      XLM = X - LENGTH/2
      ZB = Z -BCON*DEPTH
      ZDB = Z + 2/GAMMA - BCON*DEPTH
      ZDBY = ZDB**2 + Y**2
      ZBY = ZB**2 + Y**2
      K11 = CSQRT(XLP**2 + ZDBY)
      K12 = CSQRT(XLM**2 + ZDBY)
      K21 = SQRT(XLP**2 + ZBY)
      K22 = SQRT(XLM**2 + ZBY)
      COEFF = Y*CURENT * CEXP(GAMMA*ACON*DEPTH)
    3 HZ = 100.*COEFF*((XLP/K11 -XLM/K12)/ZDBY - (XLP/K21 - XLM/K22)/ZB
    4 RETURN
      END
      COMPLEX FUNCTION HT(FREQ,X,Y,Z,BETA)
      COMPLEX HX,HY,HZ
      SBETA = SIN(BETA)
      CBETA = COS(BETA)
      HT = HX(FREQ,X,Y,Z)*CBETA/1.76 -0.823*HZ(FREQ,X,Y,Z)
      HT = HT + HY(FREQ,X,Y,Z)*SBETA/1.76
      RETURN
      END
      FUNCTION HP(FREQ,X,Y,Z,BETA)
      COMPLEX HX,HY,HZ,HT
      HP = ATAN(AIMAG(HT(FREQ,X,Y,Z,BETA))/REAL(HT(FREQ,X,Y,Z,BETA)))
      RETURN
      END
      FUNCTION HR(FREQ,X,Y,Z,BETA)
      COMPLEX HX,HY,HZ
      SBETA = SIN(BETA)
      CBETA = COS(BETA)
      HR = REAL(HX(FREQ,X,Y,Z))*CBETA/1.76 - 0.823*REAL(HZ(FREQ,X,Y,Z))
      HR = HR + REAL(HY(FREQ,X,Y,Z))*SBETA/1.76
      RETURN
      END
      COMMON DEPTH,LENGTH,CURENT,ACON,BCON,PI
      COMPLEX HX,HY,HZ,HT
      REAL LENGTH
      DEPTH = -76.2
      LENGTH = 50.
      CURENT = 1.00
      PI = 3.14159
      X = -39.5
      OPEN (1,'ACFFD',ACCESS='ASCII')
      OPEN (2,'ACFPFD',ACCESS='ASCII')
```

```
      OPEN (3,'ACFTFD',ACCESS='ASCII')
      FREQ = 1
      PRINT, 'WHAT IS THE HEIGHT IN METERS'
      INPUT, Z
      PRINT, 'WHAT IS THE  LIMIT FOR Y AND ITS INCREMENT'
      INPUT, LIMIT,INC
      PRINT, 'WHAT ARE THE VALUES FOR A? AND FOR B'
      INPUT, ACON,BCON
      PRINT, 'WHAT IS THE ANGLE FOR EARTH MAGNETIC FIELD'
      INPUT, ANGLE
      BETA = ANGLE*PI
      DO 10 Y = 0.01,LIMIT,INC
      AHX = CABS(HX(FREQ,X,Y,Z))
   10 WRITE (1,100) Y,AHX
      WRITE (1,200)
      DO 20 Y = 0.01,LIMIT,INC
      AHY = CABS(HY(FREQ,X,Y,Z))
   20 WRITE (1,100) Y,AHY
      WRITE (1,200)
      DO 30 Y = 0.01,LIMIT,INC
      AHZ = CABS(HZ(FREQ,X,Y,Z))
   30 WRITE (1,100) Y, AHZ
      WRITE (1,200)
      DO 40 Y = 0.01,LIMIT,INC
      AHT = CABS(HT(FREQ,X,Y,Z,BETA))
   40 WRITE (3,100) Y, AHT
      WRITE (3,200)
      DO 50 Y = 0.01,LIMIT,INC
   50 WRITE (3,100) Y, HR(FREQ,X,Y,Z,BETA)
      WRITE (3,200)
      DO 60 Y = 0.01,LIMIT,INC
   60 WRITE (2,100) Y, HP(FREQ,X,Y,Z,BETA)
      WRITE (2,200)
      CLOSE (1)
      CLOSE (2)
      CLOSE (3)
  100 FORMAT (1PE10.3,1H,,1PE10.3)
  200 FORMAT (11H1.E37,1.E37)
      END
```

ACP

```
   *  MODIFIED IMAGE THEORY FOR INFINITESIMAL AC HED
   *  SUBSURFACE TO AIR PROPAGATION
   *  BANNISTER REPORT 5647
      COMPLEX FUNCTION HX(FREQ,X,Y,Z)
      COMPLEX ZDB,K2,HX1,HX2,GAMMA
      COMPLEX COEFF
      REAL K1-PI
      COMMON DEPTH,ACON,BCON,P,PI
      GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
      ZB = Z -BCON*DEPTH
      ZDB = Z + 2/GAMMA -BCON*DEPTH
      COEFF = P * CEXP(GAMMA*ACON*DEPTH)/(4*PI)
      RHO = SQRT(X**2 + Y**2)
      K1 = SQRT(RHO**2 + ZB**2)
      K2 = CSQRT(RHO**2 + ZDB**2)
 1    HX1 = ZDB/(K2**3) - ZB/(K1**3)
      HX2 = (ZDB/K2 - ZB/K1)*2/(RHO**2)
      HX = 400.*PI*COEFF*X*Y*(HX1 + HX2)/(RHO**2)
      RETURN
      END
      COMPLEX FUNCTION HY(FREQ,X,Y,Z)
      COMPLEX ZDB,K2,HY1,HY2,GAMMA
      COMPLEX HY1,HY2,HX1,HX2,GAMMA
      COMPLEX COEFF
      REAL K1,PI
      COMMON DEPTH,ACON,BCON,P,PI
      GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
      ZB = Z -BCON*DEPTH
      ZDB = Z + 2/GAMMA - BCON*DEPTH
      RHO = SQRT(X**2 + Y**2)
      K1 = SQRT(RHO**2 + ZB**2)
      K2 = CSQRT(RHO**2 + ZDB**2)
      COEFF = P * CEXP(GAMMA*ACON*DEPTH)/(4*PI)
 2    HY1 = (ZDB/(K2*K2*K2) - ZB/(K1*K1*K1))*X*Y/(RHO**2)
      HY2 = (ZDB/K2 - ZB/K1)*(Y**2 - X**2)/(RHO**4)
      HY = 400.*PI*COEFF*(HY1+HY2)
      END
      COMPLEX FUNCTION HZ(FREQ,X,Y,Z)
      COMPLEX ZDB,K2,GAMMA
      REAL K1,PI
      COMMON DEPTH,ACON,BCON,P,PI
      GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
      ZB = Z -BCON*DEPTH
      ZDB = Z + 2/GAMMA - BCON*DEPTH
      RHO = SQRT(X**2 + Y**2)
      K1 = SQRT(RHO**2 + ZB**2)
      K2 = CSQRT(RHO**2 + ZDB**2)
      COEFF = P * CEXP(GAMMA*ACON*DEPTH)/(4*PI)
 3    HZ = 400.*PI*Y*COEFF*(1/(K1**3) - 1/(K2**3))
 4    RETURN
      END
      COMPLEX FUNCTION HT(FREQ,X,Y,Z,BETA)
```

```
      COMPLEX HX,HY,HZ
      SBETA = SIN(BETA)
      CBETA = COS(BETA)
      HT = HX(FREQ,X,Y,Z)*CBETA/1.76 + HY(FREQ,X,Y,Z)*SBETA/1.76
      HT= HT-0.823*HZ(FREQ,X,Y,Z)
      RETURN
      END
       FUNCTION HP(FREQ,X,Y,Z,BETA)
      COMPLEX HX,HY,HZ,HT
      HP = A~AN(AIMAG(HT(FREQ,X,Y,Z,BETA))/REAL(HT(FREQ,X.Y,Z,BETA)))
      RETURN
      END
      FUNCTION HR(FREQ,X,Y,Z,BETA)
      COMPLEX HX,HY,HZ
      SBETA = SIN(BETA)
      CBETA = COS(BETA)
      HR = REAL(HX(FREQ,X,Y,Z))*CBETA/1.76
      HR = HR+REAL(HY(FREQ,X,Y,Z))*SBETA/1.76
      HR = HR - 0.823*REAL(HZ(FREQ,X,Y,Z))
      RETURN
      END
      COMMON DEPTH,ACON,BCON,P,PI
      COMPLEX HX,HY,HZ,HT
      X=-39.5
      DEPTH = -76.2
      PI = 3.14159
      P = 50.0
      OPEN (1,'ACPFD',ACCESS='ASCII')
      OPEN (2,'ACPPFD',ACCESS='ASCII')
      OPEN (3,'ACPTFD',ACCESS='ASCII')
      FREQ=1.0
      PRINT, 'WHAT IS THE HEIGHT IN METERS'
      INPUT, Z
      LIMIT=5000
      INC=100
      PRINT, 'WHAT ARE THE VALUES FOR A? AND FOR B'
      INPUT, ACON,BCON
      PRINT, 'WHAT IS THE ANGLE OF THE EARTH MAGNETIC FIELD'
      INPUT, ANGLE
      BETA = ANGLE*PI
      DO 10 Y = 0.01,LIMIT,INC
      AHX = CABS(HX(FREQ,X,Y,Z))
   10 WRITE (1,100) Y,AHX
      WRITE (1,200)
      DO 20 Y = 0.01,LIMIT,INC
      AHY = CABS(HY(FREQ,X,Y,Z))
   20 WRITE (1,100) Y, AHY
      WRITE (1,200)
      DO 30 Y = 0.01,LIMIT,INC
      AHZ = CABS(HZ(FREQ,X,Y,Z))
   30 WRITE (1,100) Y, AHZ
      WRITE (1,200)
```

```
      DO 40 Y = 0.01,LIMIT,INC
      AHT = CABS(HT(FREQ,X,Y,Z,BETA))
   40 WRITE (3,100) Y, AHT
      WRITE (3,200)
      DO 50 Y= 0.01 ,LIMIT,INC
   50 WRITE (2,100) Y, HR(FREQ,X,Y,Z,BETA)
      WRITE (2,200)
      DO 60 Y = 0.01,LIMIT,INC
   60 WRITE (3,100) Y, HR(FREQ,X,Y,Z,BETA)
      WRITE (3,200)
      CLOSE (1)
      CLOSE (2)
      CLOSE (3)
  100 FORMAT (1PE10.3,1H,,1PE10.3)
  200 FORMAT (11H1.E37,1.E37)
      END
```

```
*    MODIFIED IMAGE THEORY FOR POINT AC SUB TO SUB
*    NUSC REPORT 5647
     COMPLEX FUNCTION HX(FREQ,X,Y,Z)
     COMPLEX HX1,HX2
     COMPLEX EXP2,EXPZ,GAMMA,DZB,KFOUR
     REAL KTHREE
     COMMON DEPTH,ACON,BCON,P,PI
     GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
     ZHP = Z + DEPTH
     DZB = 2/GAMMA - BCON*ZHP
     RHO = SQRT(X**2 + Y**2)
     RTWO = SQRT(RHO**2 + ZHP**2)
     EXP2 = CEXP(-GAMMA*RTWO)
     EXPZ = CEXP(GAMMA*ACON*ZHP)
     KTHREE = SQRT(RHO**2 + (BCON*ZHP)**2)
     KFOUR = CSQRT(RHO**2 + DZB**2)
     HX1 = ZHP*(1 + GAMMA*RTWO)*EXP2/(RTWO**3)
     HX2 = 2*DZB/(KFOUR*(RHO**2)) + 2*BCON*ZHP/(KTHREE*(RHO**2))
     HX2 = HX2 + DZB/(KFOUR**3)
     HX = 100.*P*X*Y*(HX1 + EXPZ*HX2)/(RHO**2)
     RETURN
     END
     COMPLEX FUNCTION HY(FREQ,X,Y,Z)
     COMPLEX HY1,HY2,HY3,EXP1
     COMPLEX EXP2,EXPZ,GAMMA,DZB,KFOUR
     REAL KTHREE
     COMMON DEPTH,ACON,BCON,P,PI
     GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
     ZHM = Z - DEPTH
     ZHP = Z + DEPTH
     DZB = 2/GAMMA - BCON*ZHP
     RHO = SQRT(X**2 + Y**2)
     RONE = SQRT(RHO**2 + ZHM**2)
     RTWO = SQRT(RHO**2 + ZHP**2)
     EXP1 = CEXP(-GAMMA*RONE)
     EXP2 = CEXP(-GAMMA*RTWO)
     EXPZ = CEXP(GAMMA*ACON*ZHP)
     KTHREE = SQRT(RHO**2 + (BCON*ZHP)**2)
     KFOUR = CSQRT(RHO**2 + DZB**2)
     HY1 = -ZHM*(1 + GAMMA*RONE)*EXP1/(RONE**3)
     HY2 = -ZHP*(X**2)*(1 + GAMMA*RTWO)*EXP2/((RHO**2)*(RTWO**3))
     HY3 = DZB*(Y**2 - X**2)/(KFOUR*(RHO**4))
     HY3 = HY3 + BCON*ZHP*(Y**2 - X**2)/(KTHREE*(RHO**4))
     HY3 = EXPZ*(HY3 + (Y**2)*DZB/((KFOUR**3)*(RHO**2)))
     HY = 100.*P*(HY1 + HY2 + HY3)
     RETURN
     END
     COMPLEX FUNCTION HZ(FREQ,X,Y,Z)
     COMPLEX HZ1,HZ2,HZ3,EXP1
     COMPLEX EXP2,EXPZ,GAMMA,DZB,KFOUR
     REAL KTHREE
     COMMON DEPTH,ACON,BCON,P,PI
```

```
      GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
      ZHM = Z - DEPTH
      ZHP = Z + DEPTH
      DZB = 2/GAMMA - BCON*ZHP
      RHO = SQRT(X**2 + Y**2)
      RONE = SQRT(RHO**2 + ZHM**2)
      RTWO = SQRT(RHO**2 + ZHP**2)
      EXP1 = CEXP(-GAMMA*RONE)
      EXP2 = CEXP(-GAMMA*RTWO)
      EXPZ = CEXP(GAMMA*ACON*ZHP)
      KTHREE = SQRT(RHO**2 + (BCON*ZHP)**2)
      KFOUR = CSQRT(RHO**2 + DZB**2)
      HZ1 = EXP1*(1 + GAMMA*RONE)/(RONE**3)
      HZ2 = EXP2*(1 + GAMMA*RTWO)/(RTWO**3)
      HZ3 = EXPZ*(1/(KTHREE**3) - 1/(KFOUR**3))
      HZ = 100.*P*Y*(HZ1 - HZ2 + HZ3)/RHO
    4 RETURN
      END
      COMPLEX FUNCTION HT(FREQ,X,Y,Z,BETA)
      COMPLEX HX,HY,HZ
      SBETA = SIN(BETA)
      CBETA = COS(BETA)
      HT = HX(FREQ,X,Y,Z)*CBETA/1.76 - 0.823*HZ(FREQ,X,Y,Z)
      HT = HT + HY(FREQ,X,Y,Z)*SBETA/1.76
      RETURN
      END
      FUNCTION HP(FREQ,X,Y,Z,BETA)
      COMPLEX HX,HY,HZ,HT
      HP = ATAN(AIMAG(HT(FREQ,X,Y,Z,BETA))/REAL(HT(FREQ,X,Y,Z,BETA
      RETURN
      END
      FUNCTION HR(FREQ,X,Y,Z,BETA)
      COMPLEX HX,HY,HZ
      SBETA = SIN(BETA)
      CBETA = COS(BETA)
      HR = REAL(HX(FREQ,X,Y,Z))*CBETA/1.76 - 0.823*REAL(HZ(FREQ,X,Y
      HR = HR + REAL(HY(FREQ,X,Y,Z))*SBETA/1.76
      RETURN
      END
      COMMON DEPTH,ACON,BCON,P,PI
      COMPLEX HX,HY,HZ,HT
      X=76.2
      DEPTH = -76.2
      PI = 3.14159
      P = 50.0
      OPEN (1,"ACPSFD",ACCESS="ASCII")
      OPEN (2,"ACPSPFD",ACCESS="ASCII")
      OPEN(3,"ACPSTFD",ACCESS="ASCII")
      FREQ=1
      PRINT, "WHAT IS THE HEIGHT IN METERS"
      INPUT, Z
      PRINT, "WHAT IS THE UPPER LIMIT FOR Y AND ITS INCREMENT"
```

```
      INPUT, LIMIT,INC
      PRINT, 'WHAT ARE THE VALUES FOR A? AND FOR B'
      INPUT, ACON,BCON
      PRINT, 'WHAT IS THE ANGLE OF THE EARTH MAGNETIC FIELD'
      INPUT, ANGLE
      BETA = ANGLE*PI
      DO 10 Y = 0.01,LIMIT,INC
      AHX = CABS(HX(FREQ,X,Y,Z))
   10 WRITE (1,100) Y,AHX
      WRITE (1,200)
      DO 20 Y = 0.01,LIMIT,INC
      AHY = CABS(HY(FREQ,X,Y,Z))
   20 WRITE (1,100) Y, AHY
      WRITE (1,200)
      DO 30 Y = 0.01,LIMIT,INC
      AHZ = CABS(HZ(FREQ,X,Y,Z))
   30 WRITE (1,100) Y, AHZ
      WRITE (1,200)
      DO 40 Y = 0.01,LIMIT,INC
      AHT = CABS(HT(FREQ,X,Y,Z,BETA))
   40 WRITE (3,100) Y, AHT
      WRITE (3,200)
      DO 50 Y = 0.01,LIMIT,INC
   50 WRITE (3,100) Y, HR(FREQ,X,Y,Z,BETA)
      WRITE (3,200)
      DO 60 Y = 0.01,LIMIT,INC
   60 WRITE (2,100) Y,HP(FREQ,X,Y,Z,BETA)
      WRITE (2,200)
      CLOSE (1)
      CLOSE (2)
      CLOSE (3)
  100 FORMAT (1PE10.3,1H,,1PE10.3)
  200 FORMAT (11H1.E37,1.E37)
      END
```

ACP1

```
*     AC DIPOLE IN QUASI-NEAR RANGE, SUB TO AIR
*     TABLE 3.13, KRAICHMAN
      COMPLEX FUNCTION HX(FREQ,X,Y,Z)
      COMMON DEPTH,PI,P
      COMPLEX GAMMA
      RHO = SQRT(X**2 + Y**2)
      R = SQRT(RHO**2 + Z**2)
      GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
      HX = P/(2*PI*GAMMA)
      HX = HX*CEXP(GAMMA*DEPTH)/(R**3)
      HX = 400.*PI*HX*3*(1.0 - (Z**2)/(R**2))*((X*Y)/(RHO**2))
      RETURN
      END
      COMPLEX FUNCTION HY(FREQ,X,Y,Z)
      COMMON DEPTH,PI,P
      COMPLEX GAMMA
      RHO = SQRT(X**2 + Y**2)
      R = SQRT(RHO**2 + Z**2)
      GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
      HY = P/(2*PI*GAMMA)
      HY = 400.*PI*HY*CEXP(GAMMA*DEPTH)/(R**3)
      HY = HY * (2*(Y**2)-(X**2)-(3*(Z**2)*(Y**2)/(R**2)))/(RHO**2)
      RETURN
      END
      COMPLEX FUNCTION HZ(FREQ,X,Y,Z)
      COMMON DEPTH,PI,P
      COMPLEX GAMMA
      RHO = SQRT(X**2 + Y**2)
      R = SQRT(RHO**2 + Z**2)
      GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
      HZ = 3.*P/(2*PI*GAMMA*GAMMA)
      HZ = HZ*Y*CEXP(GAMMA*DEPTH)/(R**5)
      HZ = 400.*PI*HZ*(1.0+(GAMMA*Z)-5*(Z**2)/(R**2))
      RETURN
      END
      COMPLEX FUNCTION HT(FREQ,X,Y,Z,BETA)
      COMPLEX HX,HY,HZ
      SBETA = SIN(BETA)
      CBETA = COS(BETA)
      HT = HX(FREQ,X,Y,Z)*CBETA/1.76 - 0.823*HZ(FREQ,X,Y,Z)
      HT = HT + HY(FREQ,X,Y,Z)*SBETA/1.76
      RETURN
      END
      FUNCTION HP(FREQ,X,Y,Z,BETA)
      COMPLEX HX,HY,HZ,HT
      HP = ATAN(AIMAG(HT(FREQ,X,Y,Z,BETA))/REAL(HT(FREQ,X,Y,Z,BETA)))
      RETURN
      END
      FUNCTION HR(FREQ,X,Y,Z,BETA)
      COMPLEX HX,HY,HZ
      SBETA = SIN(BETA)
      CBETA = COS(BETA)
```

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```
      HR = REAL(HX(FREQ,X,Y,Z))*CBETA/1.76 - 0.823*REAL(HZ(FREQ,X,Y,Z))
      HR = HR + REAL(HY(FREQ,X,Y,Z))*SBETA/1.76
      RETURN
      END
      COMPLEX HX,HY,HZ,HT
      COMMON DEPTH,PI,P
      DEPTH = -76.2
      X=-39.5
      PI = 3.14159
      P = 50.0
      OPEN (1,"AC1FD',ACCESS="ASCII")
      OPEN (2,"AC1PFD",ACCESS="ASCII")
      OPEN (3,"AC1TFD",ACCESS="ASCII")
      FREQ=1.0
      PRINT,"WHAT IS THE HEIGHT"
      INPUT, Z
      PRINT, "WHAT IS THE  LIMIT FOR Y AND ITS INCREMENT"
      INPUT, LIMIT,INC
      PRINT, "WHAT IS THE ANGLE OF EARTH MAGNETIC FIELD"
      INPUT, ANGLE
      BETA = ANGLE * PI
      DO 10 Y = 0.01,LIMIT,INC
      AHX = CABS(HX(FREQ,X,Y,Z))
   10 WRITE(1,100) Y, AHX
      WRITE (1,200)
      DO 20 Y = 0.01,LIMIT,INC
      AHY = CABS(HY(FREQ,X,Y,Z))
   20 WRITE (1,100) Y, AHY
      WRITE (1,200)
      DO 30 Y = 0.01,LIMIT,INC
      AHZ = CABS(HZ(FREQ,X,Y,Z))
   30 WRITE (1,100) Y, AHZ
      WRITE (1,200)
      DO 40 Y = 0.01,LIMIT,INC
      AHT = CABS(HT(FREQ,X,Y,Z,BETA))
   40 WRITE (3,100) Y, AHT
      WRITE (3,200)
      DO 50 Y = 0.01,LIMIT,INC
   50 WRITE (3,100) Y, HR(FREQ,X,Y,Z,BETA)
      WRITE (3,200)
      DO 60 Y = 0.01,LIMIT,INC
   60 WRITE (2,100) Y, HP(FREQ,X,Y,Z,BETA)
      WRITE (2,200)
      CLOSE (1)
      CLOSE (2)
      CLOSE (3)
100   FORMAT (1PE10.3,1H,,1PE10.3)
200   FORMAT (11H1.E37,1.E37)
END
```

```
*  AC DIPOLE IN QUASI-NEAR RANGE
*  TABLE 3.15,KRAICHMAN
   COMPLEX FUNCTION HX(FREQ,X,Y,Z)
   COMMON DEPTH,PI,P
   COMPLEX GAMMA
   RHO = SQRT(X**2 + Y**2)
   GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
   HX = (3*P)/(2*PI*GAMMA)
   HX = HX*CEXP(GAMMA*DEPTH)/(RHO**3)
   HX = 400.*PI*HX*X*Y/(RHO**2)
   RETURN
   END
   COMPLEX FUNCTION HY(FREQ,X,Y,Z)
   COMMON DEPTH,PI,P
   COMPLEX GAMMA
   RHO = SQRT(X**2 + Y**2)
   GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
   HY = P/(2*PI*GAMMA)
   HY = 400.*PI*HY*CEXP(GAMMA*DEPTH)/(RHO**3)
   HY = HY * ((2*(Y**2))/(RHO**2) - (X**2)/(RHO**2))
   RETURN
   END
   COMPLEX FUNCTION HZ(FREQ,X,Y,Z)
   COMMON DEPTH,PI,P
   COMPLEX GAMMA
   RHO = SQRT(X**2 + Y**2)
   GAMMA = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
   HZ = 3.*P/(2*PI*GAMMA*GAMMA)
   HZ = HZ*Y*CEXP(GAMMA*DEPTH)/(RHO**5)
   HZ = 400.*PI*HZ*(1.0 + GAMMA*Z)
   RETURN
   END
   COMPLEX FUNCTION HT(FREQ,X,Y,Z,BETA)
   COMPLEX HX,HY,HZ
   SBETA = SIN(BETA)
   CBETA = COS(BETA)
   HT = HX(FREQ,X,Y,Z)*CBETA/1.76 - 0.823*HZ(FREQ,X,Y,Z)
   HT = HT + HY(FREQ,X,Y,Z)*SBETA/1.76
   RETURN
   END
   FUNCTION HP(FREQ,X,Y,Z,BETA)
   COMPLEX HX,HY,HZ,HT
   HP = ATAN(AIMAG(HT(FREQ,X,Y,Z,BETA))/REAL(HT(FREQ,X,Y,Z,BETA)))
   RETURN
   END
   FUNCTION HR(FREQ,X,Y,Z,BETA)
   COMPLEX HX,HY,HZ
   SBETA = SIN(BETA)
   CBETA = COS(BETA)
   HR = REAL(HX(FREQ,X,Y,Z))*CBETA/1.76 - 0.823*REAL(HZ(FREQ,X,Y,Z))
   HR = HR + REAL(HY(FREQ,X,Y,Z))*SBETA/1.76
   RETURN
```

```
      END
      COMPLEX HX,HY,HZ,HT
      COMMON DEPTH,PI,P
      DEPTH = -76.2
      X = 152.4
      PI = 3.14159
      P = 50.0
      OPEN (1,"ACP2FD",ACCESS="ASCII")
      OPEN (2,"ACP2PFD",ACCESS="ASCII")
       OPEN (3,"ACP2TFD",ACCESS="ASCII")
      FREQ = 1.
      PRINT,"WHAT IS THE HEIGHT"
      INPUT, Z
      PRINT, "WHAT IS THE  LIMIT FOR Y AND ITS INCREMENT"
      INPUT, LIMIT,INC
      PRINT, "WHAT IS THE ANGLE OF THE EARTH MAGNETIC FIELD"
      INPUT, ANGLE
      BETA = ANGLE*PI
      DO 10 Y = 0.01,LIMIT,INC
      AHX = CABS(HX(FREQ,X,Y,Z))
   10 WRITE(1,100) Y, AHX
      WRITE (1,200)
      DO 20 Y = 0.01,LIMIT,INC
      AHY = CABS(HY(FREQ,X,Y,Z))
   20 WRITE (1,100) Y, AHY
      WRITE (1,200)
      DO 30 Y = 0.01,LIMIT,INC
      AHZ = CABS(HZ(FREQ,X,Y,Z))
   30 WRITE (1,100) Y, AHZ
      WRITE (1,200)
      DO 40 Y = 0.01,LIMIT,INC
      AHT = CABS(HT(FREQ,X,Y,Z,BETA))
   40 WRITE (3,100) Y, AHT
      WRITE (3,200)
      DO 50 Y = 0.01,LIMIT,INC
   50 WRITE (3,100) Y, HR(FREQ,X,Y,Z,BETA)
      WRITE (3,200)
      DO 60 Y = 0.01,LIMIT,INC
   60 WRITE (2,100) Y, HP(FREQ,X,Y,Z,BETA)
      WRITE (2,200)
      CLOSE (1)
      CLOSE (2)
      CLOSE (3)
100   FORMAT (1PE10.3,1H,,1PE10.3)
200   FORMAT (11H1.E37,1.E37)
      END
```

```
*    POINT AC SUB TO SUB
*    TABLE 3.16
     COMPLEX FUNCTION HX(FREQ,X,Y,Z)
     COMMON DEPTH,PI,P
     COMPLEX GAMMA1
     RZERO = SQRT(X**2 + Y**2)
     GAMMA1 = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
     HX = P/(2*PI*GAMMA1)
     HX = HX*CEXP(GAMMA1*(DEPTH + Z))/(RZERO**3)
     HX = 400.*PI*HX*3*((X*Y)/(RZERO**2))
     RETURN
     END
     COMPLEX FUNCTION HY(FREQ,X,Y,Z)
     COMMON DEPTH,PI,P
     COMPLEX GAMMA1
     RZERO = SQRT(X**2 + Y**2)
     GAMMA1 = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
     HY = P/(2*PI*GAMMA1)
     HY = 400.*PI*HY*CEXP(GAMMA1*(DEPTH + Z))/(RZERO**3)
     HY = HY * (2*(Y**2) - (X**2) )/(RZERO**2)
     RETURN
     END
     COMPLEX FUNCTION HZ(FREQ,X,Y,Z)
     COMMON DEPTH,PI,P
     COMPLEX GAMMA1
     RZERO = SQRT(X**2 + Y**2)
     GAMMA1 = CSQRT(CMPLX(0.0,FREQ*(PI**2)*32.E-7))
     HZ = 3.*P/(2*PI*GAMMA1*GAMMA1)
     HZ = HZ*Y*CEXP(GAMMA1*(DEPTH + Z))/(RZERO**5)
     HZ = 400.*PI*HZ
     RETURN
     END
     COMPLEX FUNCTION HT(FREQ,X,Y,Z,BETA)
     COMPLEX HX,HY,HZ
     SBETA = SIN(BETA)
     CBETA = COS(BETA)
     HT = HX(FREQ,X,Y,Z)*CBETA/1.76 - 0.823*HZ(FREQ,X,Y,Z)
     HT = HT + HY(FREQ,X,Y,Z)*SBETA/1.76
     RETURN
     END
     FUNCTION HP(FREQ,X,Y,Z,BETA)
     COMPLEX HX,HY,HZ,HT
     HP = ATAN(AIMAG(HT(FREQ,X,Y,Z,BETA))/REAL(HT(FREQ,X,Y,Z,BETA)))
     RETURN
     END
     FUNCTION HR(FREQ,X,Y,Z,BETA)
     COMPLEX HX,HY,HZ
     SBETA = SIN(BETA)
     CBETA = COS(BETA)
     HR = REAL(HX(FREQ,X,Y,Z))*CBETA/1.76 - 0.823*REAL(HZ(FREQ,X,Y,Z))
     HR = HR + REAL(HY(FREQ,X,Y,Z))*SBETA/1.76
     RETURN
```

```
      END
      COMPLEX HX,HY,HZ,HT
      DEPTH = -76.2
      COMMON DEPTH,PI,P
      X = 152.4
      PI = 3.14159
      P = 50.0
      OPEN (1,"ACP2SFD",ACCESS="ASCII")
      OPEN (2,"ACP2SPFD",ACCESS= "ASCII")
      OPEN (3,"ACP2STFD",ACCESS="ASCII")
      FREQ = 1.
      PRINT,"WHAT IS THE HEIGHT"
      INPUT, Z
      PRINT, "WHAT IS THE UPPER LIMIT FOR Y AND ITS INCREMENT"
      INPUT, LIMIT,INC
      PRINT,"WHAT IS THE ANGLE FOR EARTH MAGNETIC FIELD"
      INPUT, ANGLE
      BETA = ANGLE*PI
      DO 10 Y = 0.01,LIMIT,INC
      AHX = CABS(HX(FREQ,X,Y,Z))
   10 WRITE(1,100) Y, AHX
      WRITE (1,200)
      DO 20 Y = 0.01,LIMIT,INC
      AHY = CABS(HY(FREQ,X,Y,Z))
   20 WRITE (1,100) Y, AHY
      WRITE (1,200)
      DO 30 Y = 0.01,LIMIT,INC
      AHZ = CABS(HZ(FREQ,X,Y,Z))
   30 WRITE (1,100) Y, AHZ
      WRITE (1,200)
      DO 40 Y = 0.01,LIMIT,INC
      AHT = CABS(HT(FREQ,X,Y,Z,BETA))
   40 WRITE (3,100) Y, AHT
      WRITE (3,200)
      DO 50 Y = 0.01,LIMIT,INC
   50 WRITE (3,100) Y, HR(FREQ,X,Y,Z,BETA)
      WRITE (3,200)
      DO 60 Y = 0.01,LIMIT,INC
   60 WRITE (2,100) Y, HP(FREQ,X,Y,Z,BETA)
      WRITE (2,200)
      CLOSE (1)
      CLOSE (2)
      CLOSE (3)
100   FORMAT (1PE10.3,1H,,1PE10.3)
200   FORMAT (11H1.E37,1.E37)
      END
```

DCP

```
*  INFINITESIMAL DC HED
    FUNCTION HX(X,Y,Z)
   COMMON DEPTH,P
   ZH = Z - DEPTH
   RHO = SQRT(X**2 + Y**2)
   RONE = SQRT(RHO**2 + ZH**2)
   HX = (P*X*Y)/(RHO**2)
   HX = 100.*HX*(ZH/(RONE*(RONE**2)) + 2*(ZH/RONE -1)/(RHO**2))
   RETURN
   END
    FUNCTION HY(X,Y,Z)
   COMMON DEPTH,P
   ZH = Z - DEPTH
   RHO = SQRT(X**2 + Y**2)
   RONE = SQRT(RHO**2 + ZH**2)
   HY = -(ZH*(Y**2))/(RONE**3) + (X**2 - Y**2)*(ZH/RONE - 1)/(RHO**
   HY =100.*P*HY/(RHO**2)
   RETURN
   END
    FUNCTION HZ(X,Y,Z)
   COMMON DEPTH,P
   ZH = Z - DEPTH
   RHO = SQRT(X**2 + Y**2)
   RONE = SQRT(RHO**2 + ZH**2)
   HZ = 100*P*Y/(RONE*(RONE**2))
   RETURN
   END
   FUNCTION HT(X,Y,Z,BETA)
   SBETA = SIN(BETA)
   CBETA = COS(BETA)
   HT = HX(X,Y,Z)*CBETA/1.76 + HY(X,Y,Z)*SBETA/1.76 - 0.823*HZ(
   RETURN
   END
   COMMON DEPTH,P
   DEPTH=-76.2
   X=-152.4
   P = 50.0
   PI = 3.14159
   OPEN (1,"DC1FIELD",ACCESS="ASCII")
   ENDFILE 1
   PRINT,"WHAT IS THE HEIGHT"
   INPUT, Z
   PRINT, "WHAT IS THE  LIMIT FOR Y AND ITS INCREMENT"
   INPUT, LIMIT,INC
   PRINT, "WHAT IS THE ANGLE OF THE EARTH MAGNETIC FIELD"
   INPUT, ANGLE
   BETA = ANGLE*PI
   DO 10 Y = -LIMIT,LIMIT,INC
10 WRITE (1,100) Y,HX(X,Y,Z)
   WRITE (1,400)
   DO 20 Y = -LIMIT,LIMIT,INC
20 WRITE (1,100) Y, HY(X,Y,Z)
```

```
      WRITE (1,400)
      DO 30 Y = -LIMIT,LIMIT,INC
   30 WRITE (1,100) Y,HZ(X,Y,Z)
      WRITE (1,400)
      DO 40 Y = -LIMIT,LIMIT,INC
   40 WRITE (1,100) Y,HT(X,Y,Z,BETA)
      WRITE (1,400)
      CLOSE (1)
100   FORMAT (1PE10.3,1H,,1PE10.3)
400   FORMAT (11H1.E37,1.E37)
      END
```

```
* MODIFIED IMAGE FOR FINITE LENGTH DC HED
      FUNCTION HX(X,Y,Z)
      COMMON BCON,DEPTH,CURENT,LENGTH
      REAL LENGTH
      REAL K21,K22
      XLP = X + LENGTH/2
      XLM = X - LENGTH/2
      ZB = Z -BCON*DEPTH
      XLPY = XLP**2 + Y**2
      XLMY = XLM**2 + Y**2
      ZBY = ZB**2 + Y**2
      K21 = SQRT(XLP**2 + ZBY)
      K22 = SQRT(XLM**2 + ZBY)
 1    HX1 = (1 - ZB/K22)/XLMY
      HX2 = (1 - ZB/K21)/XLPY
      HX = 100*Y*CURENT*(HX1 - HX2)
      RETURN
      END
      FUNCTION HY(X,Y,Z)
      COMMON BCON,DEPTH,CURENT,LENGTH
      REAL K21,K22
      REAL LENGTH
      XLP = X + LENGTH/2
      XLM = X - LENGTH/2
      ZB = Z -BCON*DEPTH
      XLPY = XLP**2 + Y**2
      XLMY = XLM**2 + Y**2
      ZBY = ZB**2 + Y**2
      K21 = SQRT(XLP**2 + ZBY)
      K22 = SQRT(XLM**2 + ZBY)
 2    HY1 = (XLP/K21 - XLM/K22)*ZB/ZBY
      HY2 = XLP*(1 - ZB/K21)/XLPY
      HY3 = XLM*(1 - ZB/K22)/XLMY
      HY = 100.*CURENT*(-HY1 + HY2 - HY3)
      RETURN
      END
      FUNCTION HZ(X,Y,Z)
      COMMON BCON,DEPTH,CURENT,LENGTH
      REAL K21,K22
      REAL LENGTH
      XLP = X + LENGTH/2
      XLM = X - LENGTH/2
      ZB = Z -BCON*DEPTH
      ZBY = ZB**2 + Y**2
      K21 = SQRT(XLP**2 + ZBY)
      K22 = SQRT(XLM**2 + ZBY)
 3    HZ = 100*Y*CURENT*(XLP/K21 - XLM/K22)/ZBY
      RETURN
      END
      FUNCTION HT(X,Y,Z,BETA)
      SBETA = SIN(BETA)
      CBETA = COS(BETA)
```

```
      HT = HX(X,Y,Z)*CBETA/1.76 + HY(X,Y,Z)*SBETA/1.76 - 0.823*HZ(X,Y,Z)
      RETURN
      END
      REAL LENGTH
      COMMON BCON,DEPTH,CURENT,LENGTH
      DEPTH=-76.2
      CURENT = 1.00
      BCON = 1.00
      LENGTH = 50.0
      X=304.8
      PI = 3.14159
      OPEN (1,"DCFIELD",ACCESS="ASCII")
      ENDFILE 1
      PRINT, "WHAT IS THE HEIGHT IN METERS"
      INPUT, Z
      PRINT, "WHAT IS THE LIMIT FOR Y AND ITS INCREMENT"
      INPUT, LIMIT,INC
      PRINT, "WHAT IS THE ANGLE FOR EARTH MAGNETIC FIELD"
      INPUT, A
      BETA = A*PI
      DO 10 Y = -LIMIT,LIMIT,INC
   10 WRITE (1,100) Y,HX(X,Y,Z)
      WRITE (1,200)
      DO 20 Y = -LIMIT,LIMIT,INC
   20 WRITE (1,100) Y,HY(X,Y,Z)
      WRITE (1,200)
      DO 30 Y = -LIMIT,LIMIT,INC
   30 WRITE (1,100) Y, HZ(X,Y,Z)
      WRITE (1,200)
      DO 40 Y = -LIMIT,LIMIT,INC
   40 WRITE (1,100) Y,HT(X,Y,Z,BETA)
      WRITE (1,200)
      CLOSE (1)
  100 FORMAT (1PE10.3,1H,,1PE10.3)
  200 FORMAT (11H1.E37,1.E37)
      END
```

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DCPS

```
*  INFINITESIMAL DC HED FROM SUBSURFACE TO SUBSURFACE
*  FORMULAE (3.18) - (3.20)
    FUNCTION HX(X,Y,Z)
   COMMON DEPTH,P
   ZHP = Z + DEPTH
   RHO = SQRT(X**2 + Y**2)
   RTWO = SQRT(RHO**2 + ZHP**2)
   HX = (P*X*Y)/(RHO**2)
   HX = 100.*HX*(ZHP/(RTWO**3) + 2*(ZHP/RTWO + 1)/(RHO**2))
   RETURN
   END
    FUNCTION HY(X,Y,Z)
   COMMON DEPTH,P
   ZH = Z - DEPTH
   ZHP = Z + DEPTH
   RHO = SQRT(X**2 + Y**2)
   RONE = SQRT(RHO**2 + ZH**2)
   RTWO = SQRT(RHO**2 + ZHP**2)
   HY1 = ZH/(RONE**3) + ZHP*(X**2)/((RHO**2)*(RTWO**3))
   HY2 = (ZHP/RTWO + 1)*(X**2 - Y**2)/(RHO**4)
   HY = -100.*P*(HY1+HY2)
   RETURN
   END
    FUNCTION HZ(X,Y,Z)
   COMMON DEPTH,P
   ZH = Z - DEPTH
   RHO = SQRT(X**2 + Y**2)
   RONE = SQRT(RHO**2 + ZH**2)
   HZ = 100*P*Y/(RONE*(RONE**2))
   RETURN
   END
   FUNCTION HT(X,Y,Z,BETA)
   SBETA = SIN(BETA)
   CBETA = COS(BETA)
   HT = HX(X,Y,Z)*CBETA/1.76 + HY(X,Y,Z)*SBETA/1.76 - 0.823*HZ(X,Y,Z)
   RETURN
   END
   COMMON DEPTH,P
   DEPTH=-76.2
   X=1
   P = 50.0
   PI = 3.14159
   OPEN (1,'DCSUBFD',ACCESS='ASCII')
   ENDFILE 1
   PRINT,'WHAT IS THE HEIGHT'
   INPUT, Z
   PRINT, 'WHAT IS THE  LIMIT FOR Y AND ITS INCREMENT'
   INPUT, LIMIT,INC
   PRINT, 'WHAT IS THE ANGLE OF THE EARTH MAGNETIC FIELD'
   INPUT, ANGLE
   BETA = ANGLE*PI
   DO 10 Y= -LIMIT,LIMIT,INC
```

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```
  10  WRITE (1,100) Y,HX(X,Y,Z)
      WRITE (1,400)
      DO 20 Y= -LIMIT,LIMIT,INC
  20  WRITE (1,100) Y, HY(X,Y,Z)
      WRITE (1,400)
      DO 30 Y= -LIMIT,LIMIT,INC
  30  WRITE (1,100) Y,HZ(X,Y,Z)
      WRITE (1,400)
      DO 40 Y= -LIMIT,LIMIT,INC
  40  WRITE (1,100) Y,HT(X,Y,Z,BETA)
      WRITE (1,400)
      CLOSE (1)
 100  FORMAT (1PE10.3,1H,,1PE10.3)
 400  FORMAT (11H1.E37,1.E37)
      END
```